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(54) **TRANSDUCER/FLEXURE/CONDUCTOR
STRUCTURE FOR ELECTROMAGNETIC
READ/WRITE SYSTEM**

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(63) Continuation of application No. 08/338,394, filed on Nov. 14, 1994, now Pat. No. 6,600,631, which is a continuation-in-part of application No. 08/191,967, filed on Feb. 4, 1994, now abandoned, which is a continuation-in-part of application No. 07/919,302, filed on Jul. 23, 1992, now abandoned, which is a continuation-in-part of application No. 07/806,611, filed on Dec. 12, 1991, now Pat. No. 5,174,012, which is a continuation of application No. 07/632,958, filed on Dec. 21, 1990, now Pat. No. 5,073,242, which is a continuation of application No. 07/441,716, filed on Nov. 27, 1989, now Pat. No. 5,041,932. Continuation-in-part of application No. 07/990,005, filed on Dec. 10, 1992, now abandoned, which is a continuation of application No. 07/746,916, filed on

Aug. 19, 1991, now abandoned, and which is a continuation-in-part of application No. 07/966,095, filed on Oct. 22, 1992, now Pat. No. 5,550,691, which is a continuation-in-part of application No. 07/783,509, filed on Oct. 28, 1991, now abandoned, and which is a continuation-in-part of application No. 07/783,619, filed on Oct. 28, 1991, now Pat. No. 5,490,027.

Continuation-in-part of application No. 08/179,758, filed on Jan. 7, 1994, now abandoned, which is a continuation of application No. 07/684,025, filed on Apr. 10, 1991, now abandoned.

Continuation-in-part of application No. 08/017,984, filed on Feb. 12, 1993, now abandoned, which is a continuation of application No. 07/770,593, filed on Oct. 3, 1991, now abandoned.

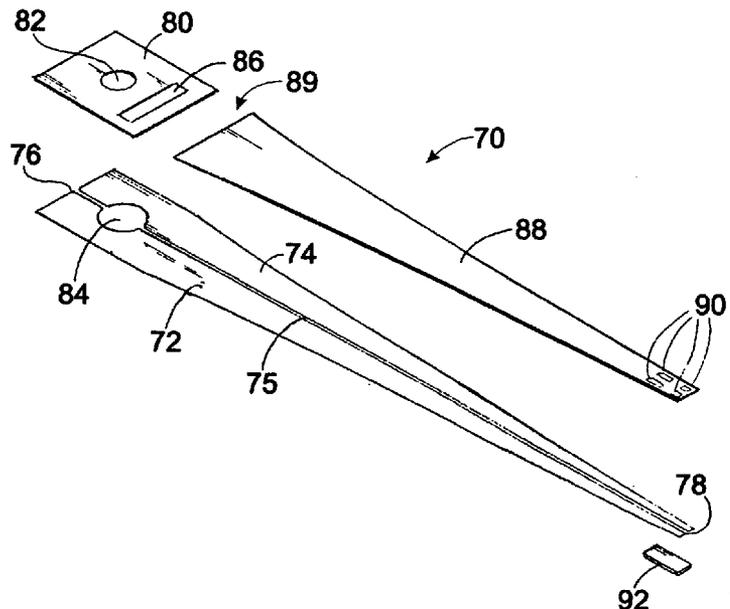
Continuation-in-part of application No. 08/180,540, filed on Jan. 12, 1994, now abandoned, which is a continuation-in-part of application No. 07/760,586, filed on Sep. 16, 1991, now abandoned.

Publication Classification

(51) **Int. Cl.⁷** **G11B 5/48; G11B 5/596**
(52) **U.S. Cl.** **360/245.9**

(57) **ABSTRACT**

Flexure/transducer structure employable in an electromagnetic information storage and retrieval system wherein mechanical load-bearing responsibilities and electrical-current-carrying responsibilities are merged into and shared by common structure. The invention subject matter is useable in systems characterized by contact operation, as well as by quasi-contact and noncontact operations, in relation to the recording surface in an information recording medium.



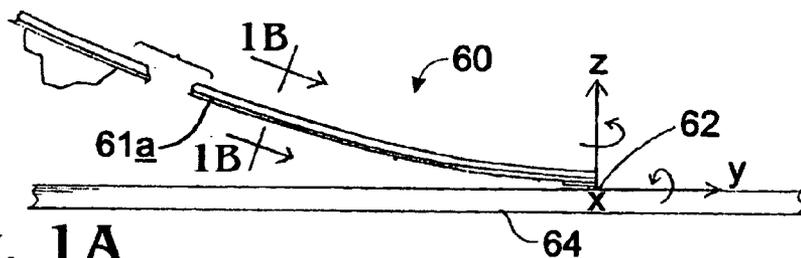


Fig. 1A

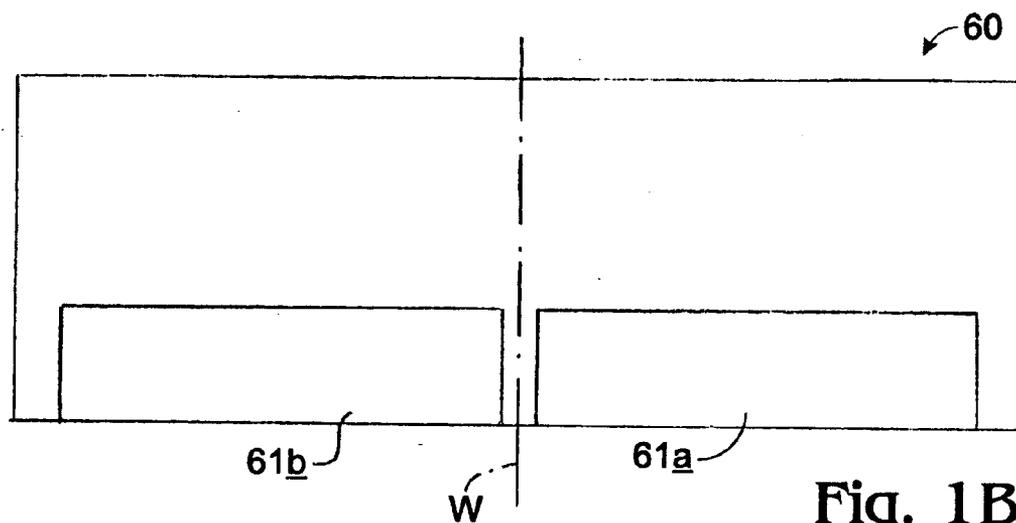


Fig. 1B

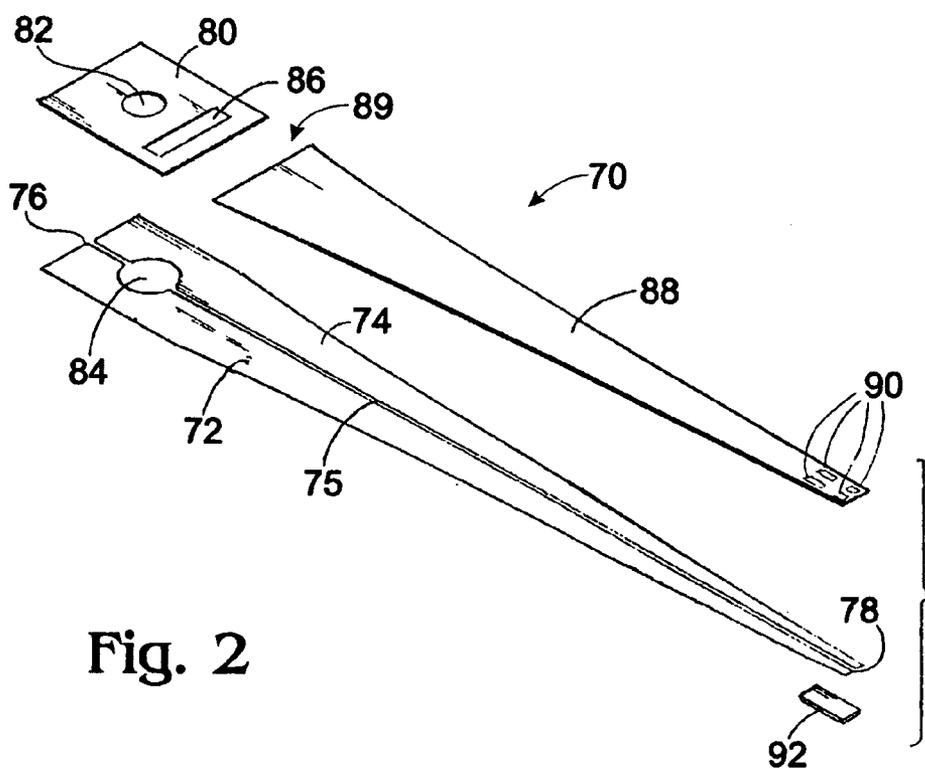
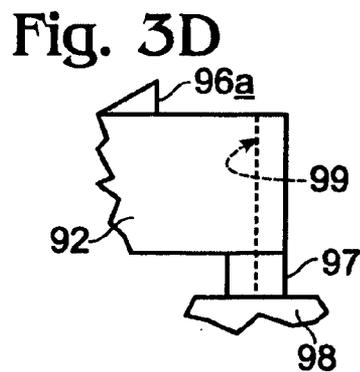
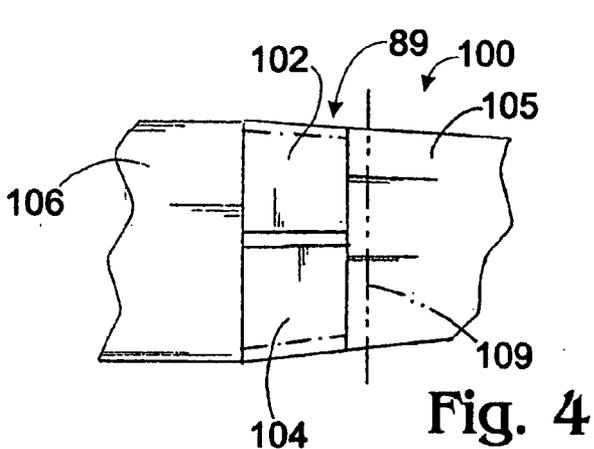
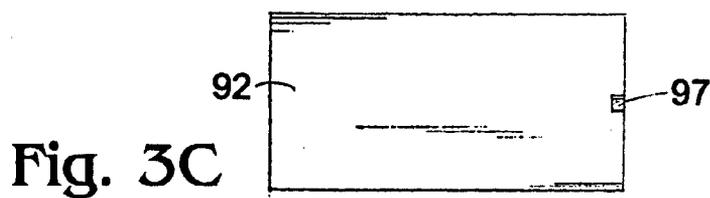
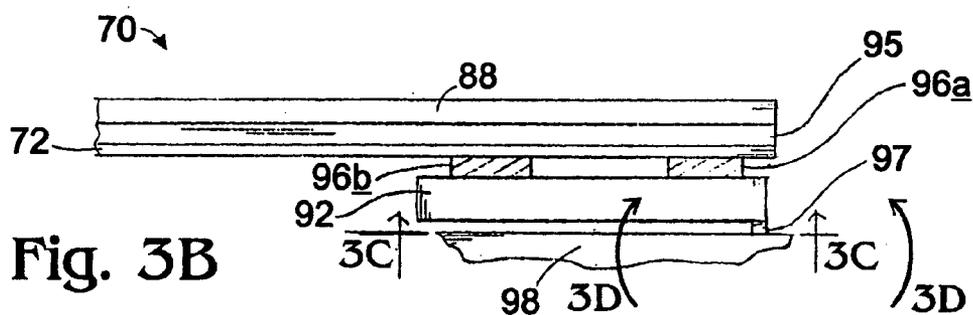
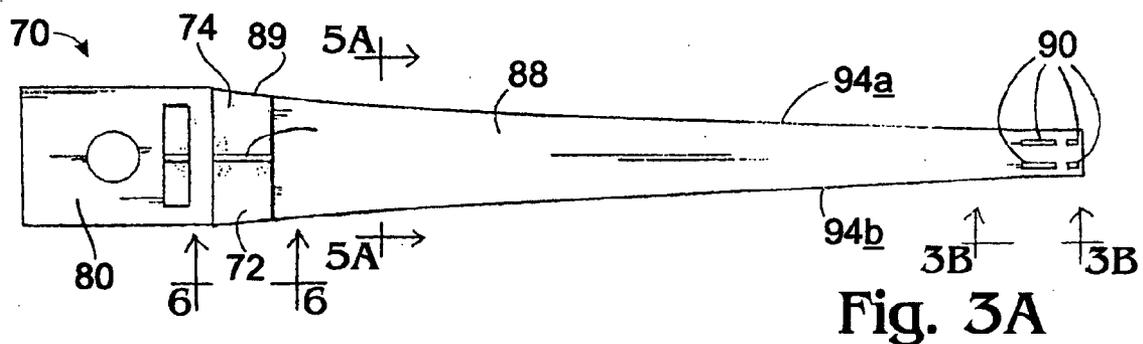


Fig. 2



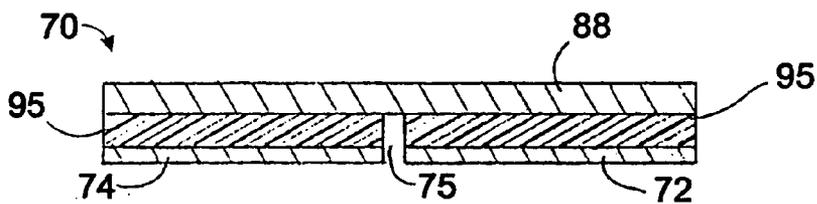


Fig. 5A

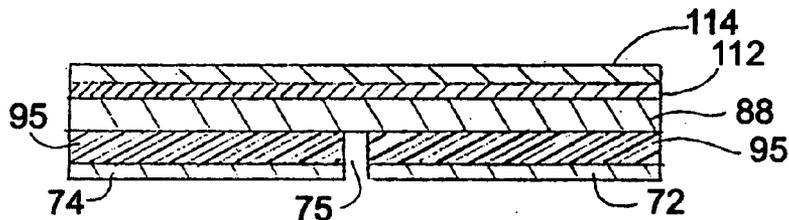


Fig. 5B

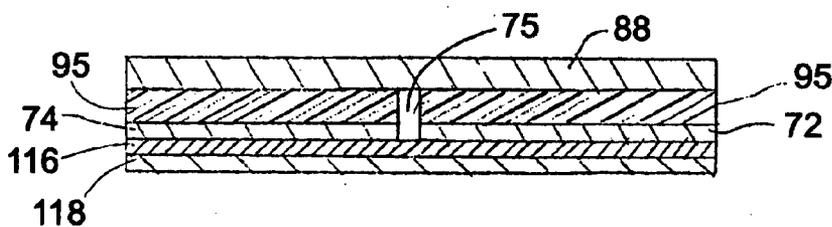


Fig. 5C

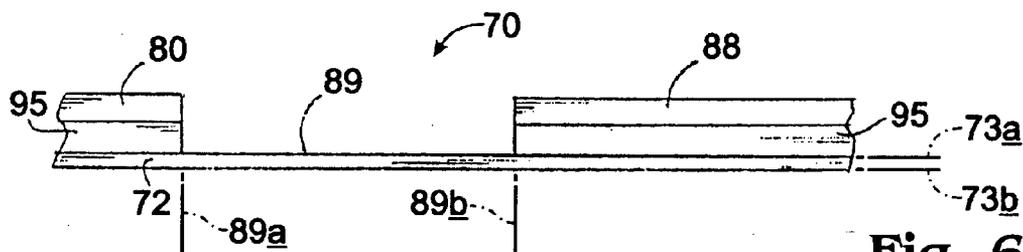


Fig. 6

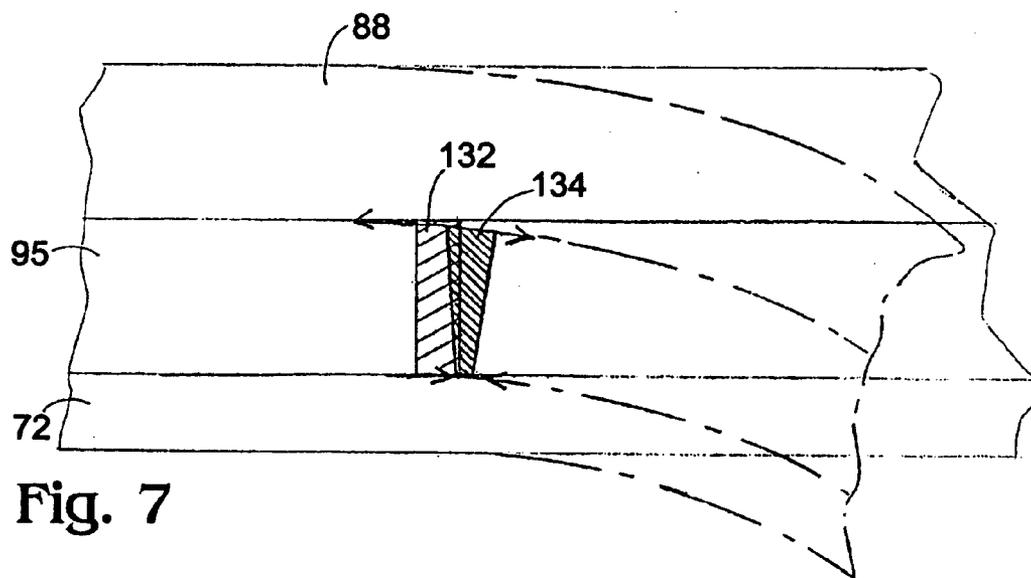


Fig. 7

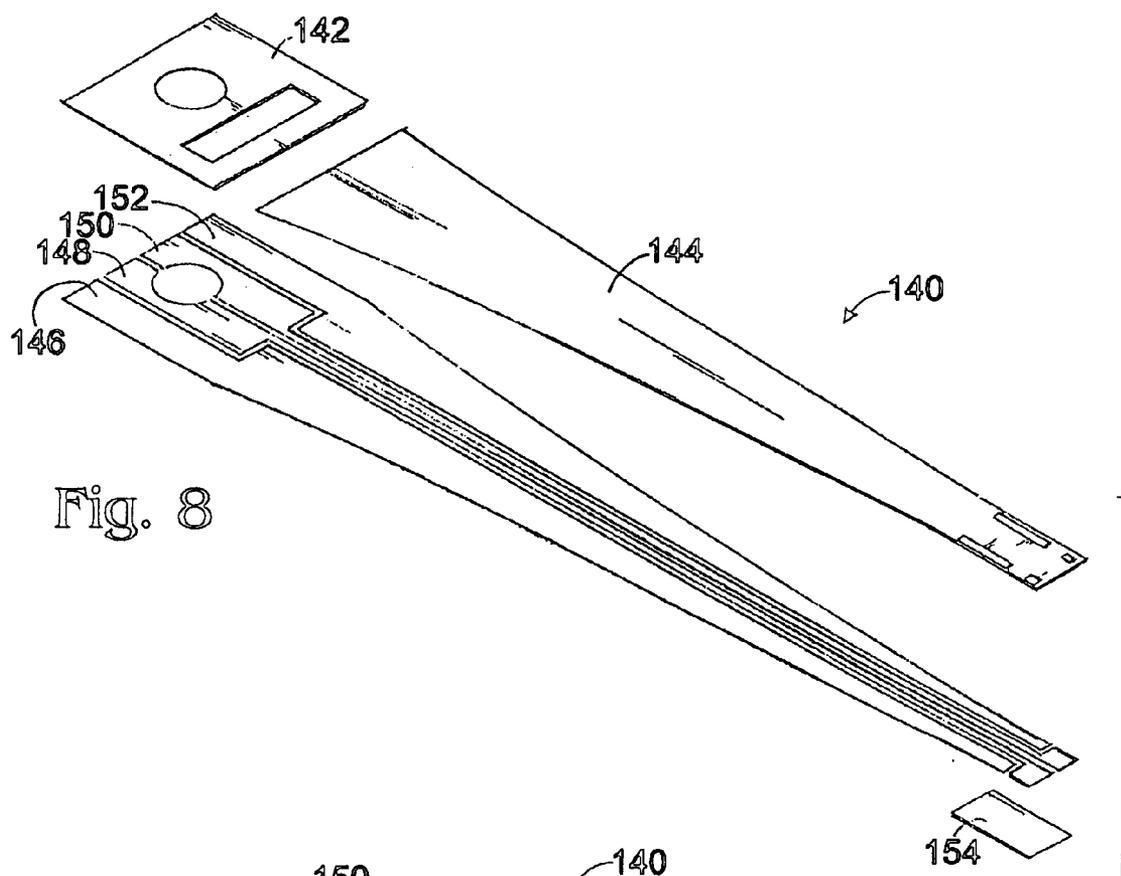


Fig. 8

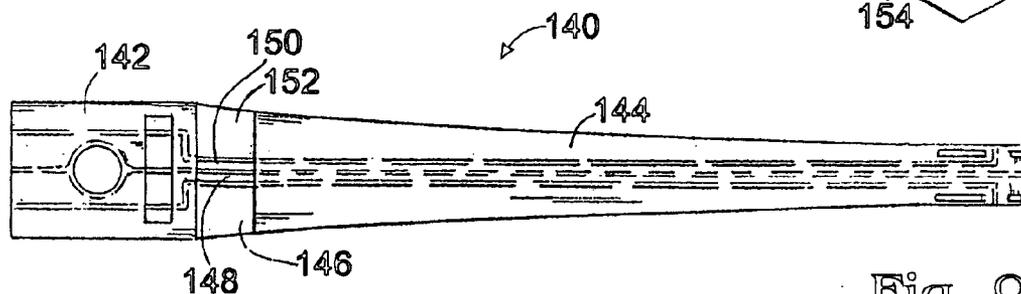


Fig. 9

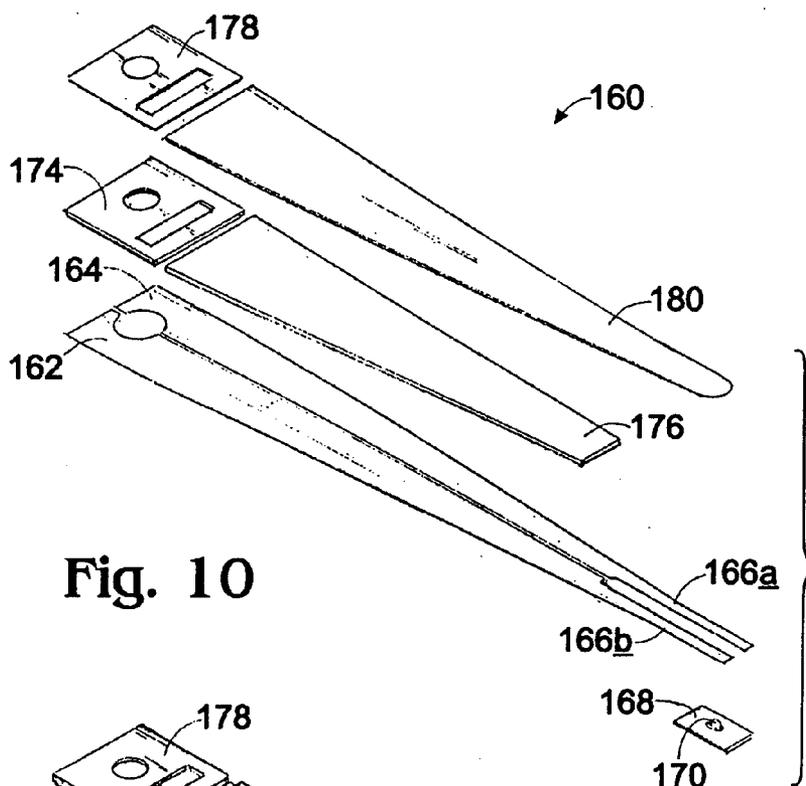


Fig. 10

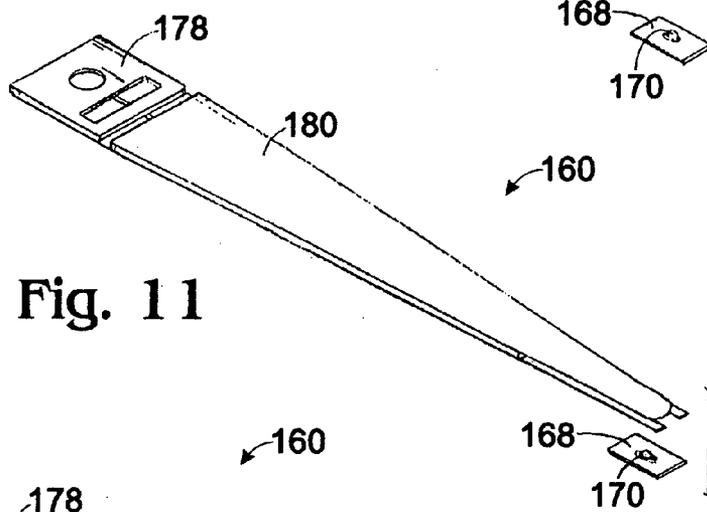


Fig. 11

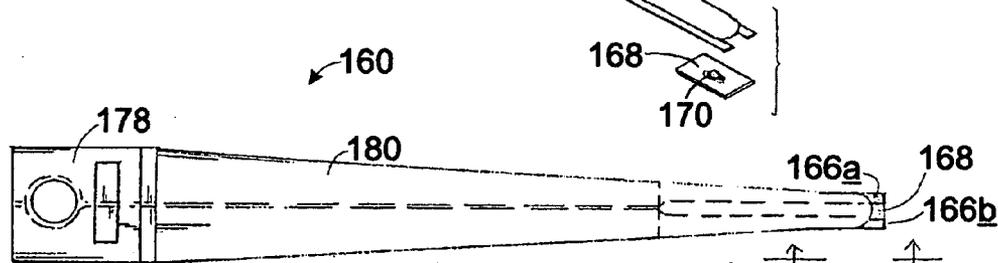


Fig. 12A

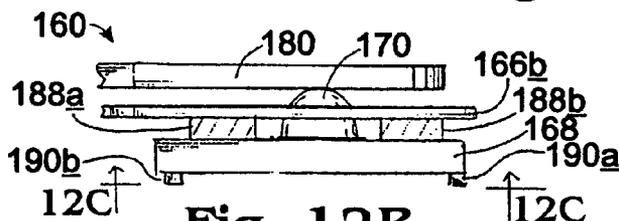


Fig. 12B

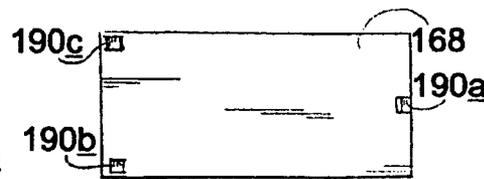


Fig. 12C

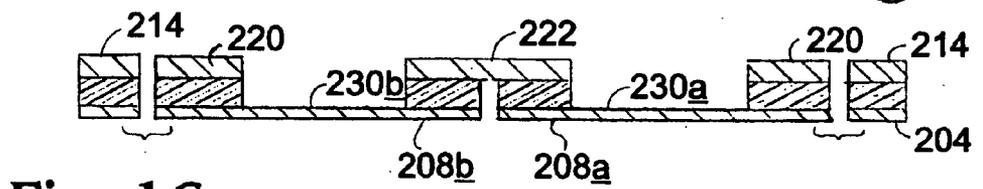
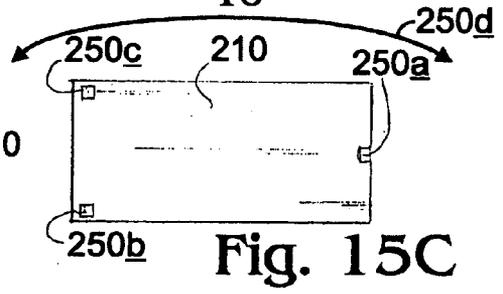
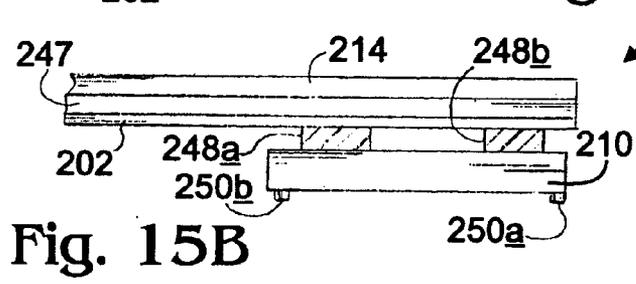
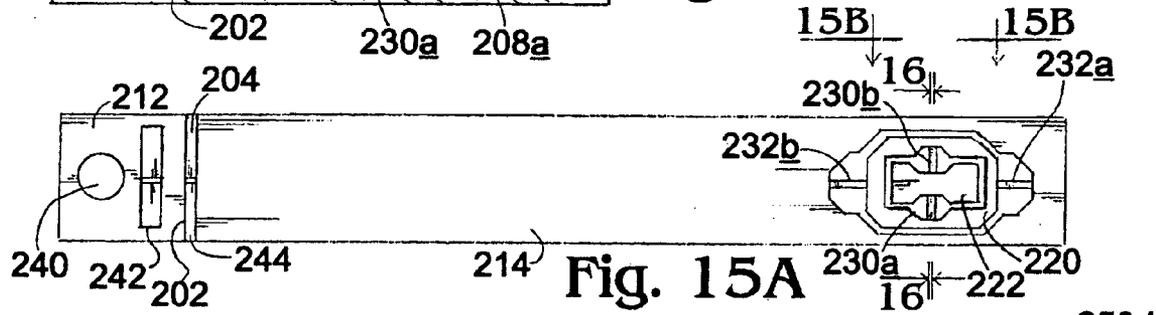
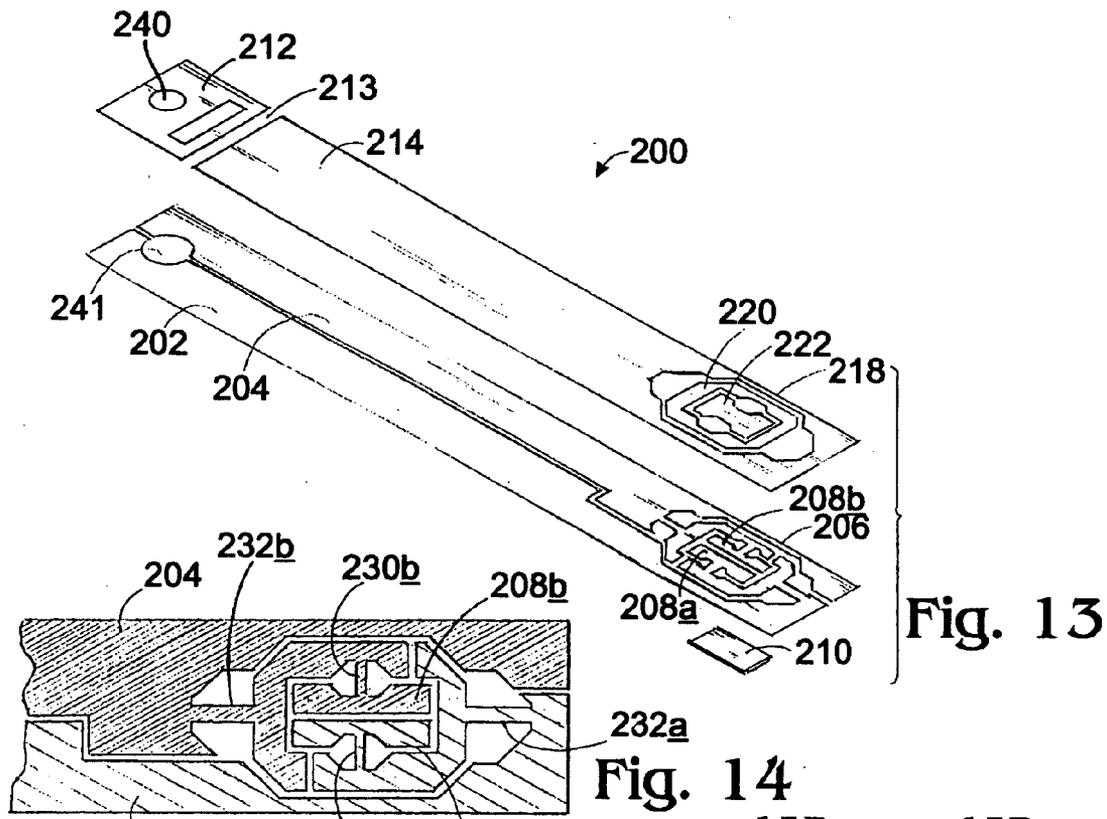


Fig. 16

Fig. 15D

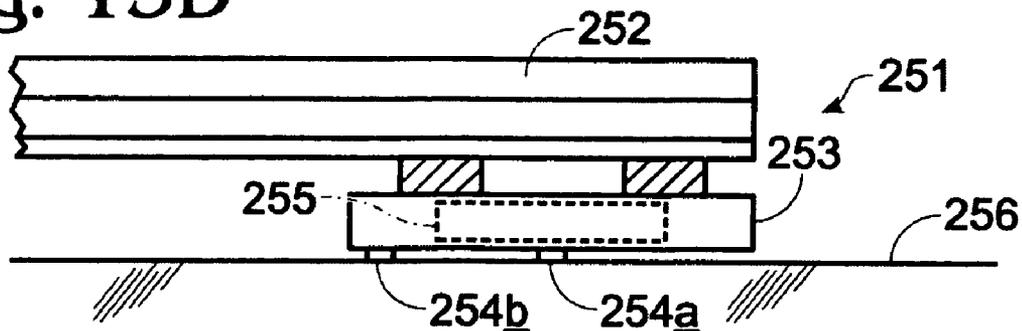


Fig. 15E

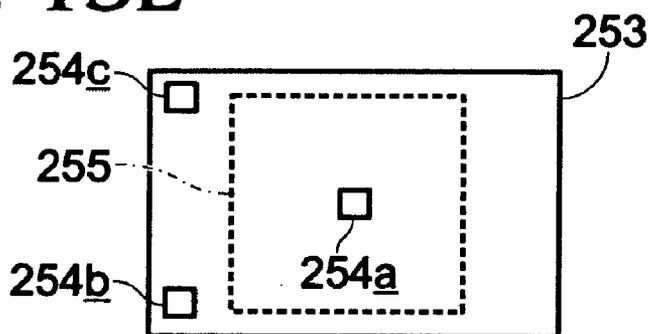
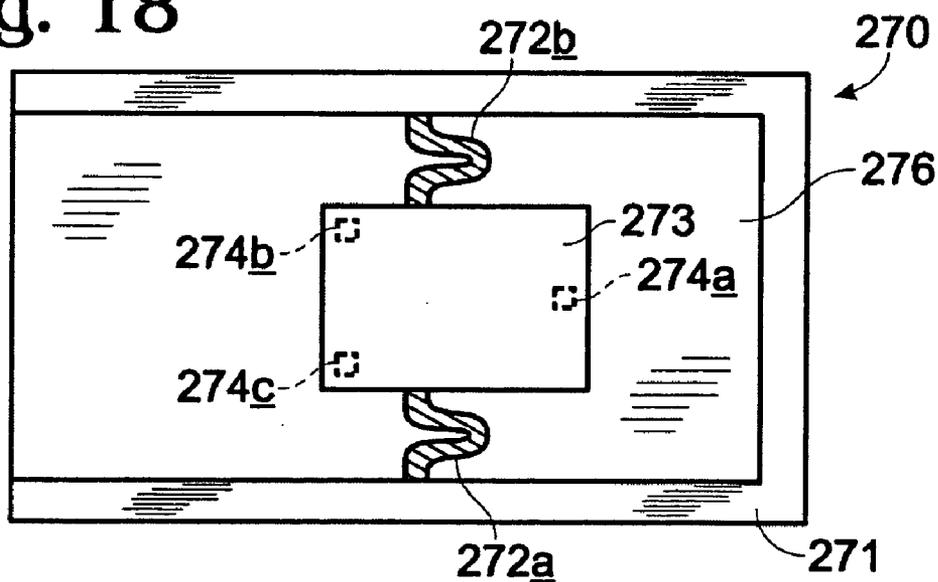


Fig. 18



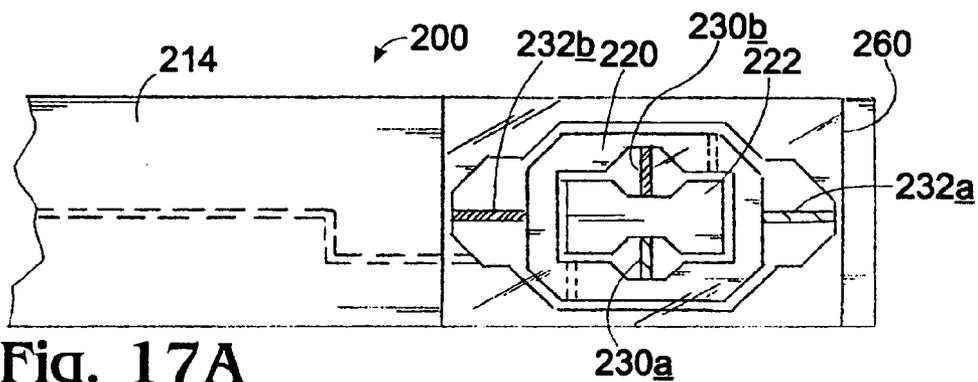


Fig. 17A

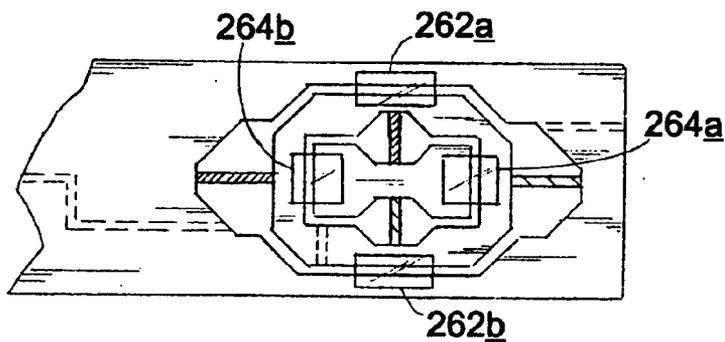


Fig. 17B

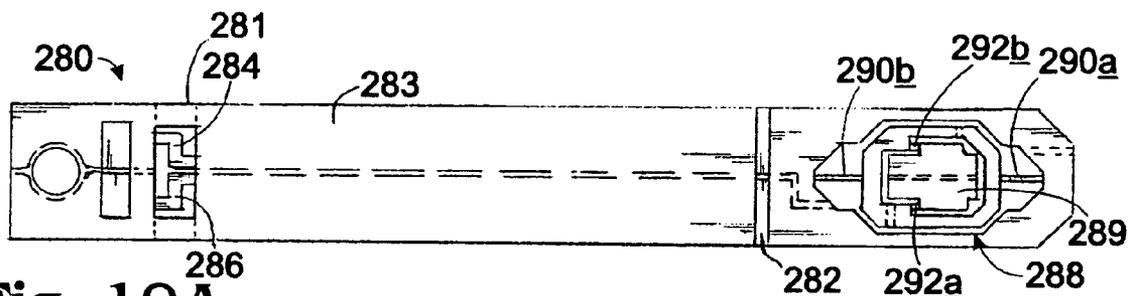


Fig. 19A

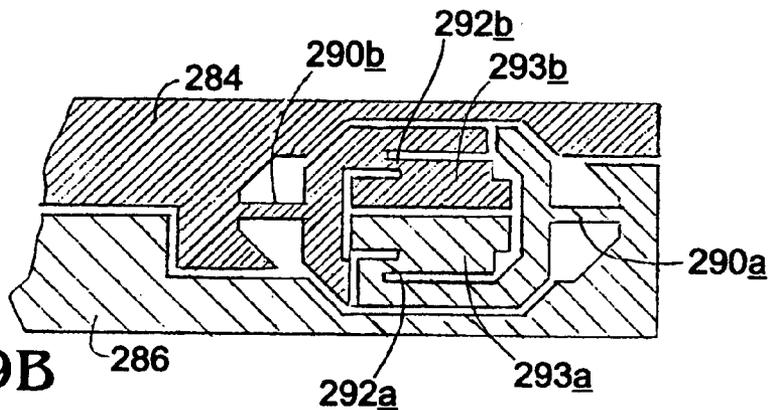


Fig. 19B

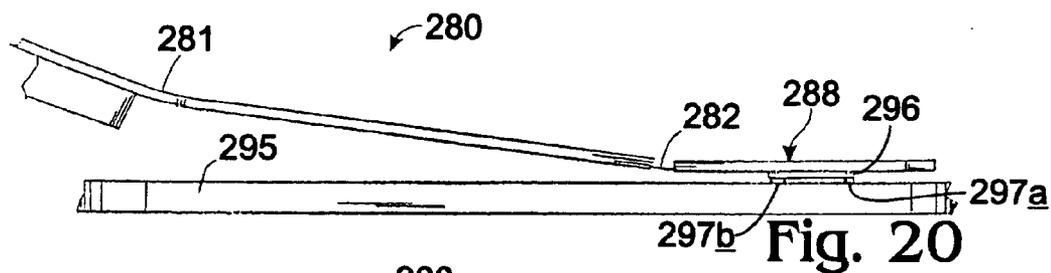


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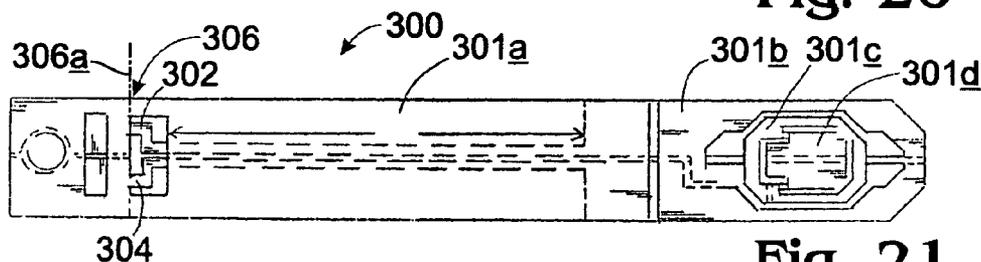


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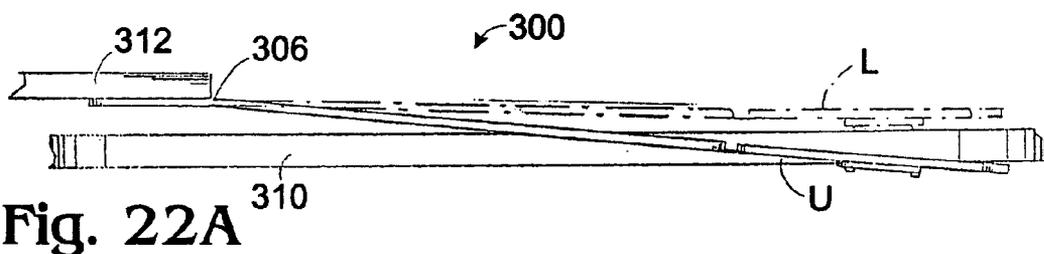


Fig. 22A

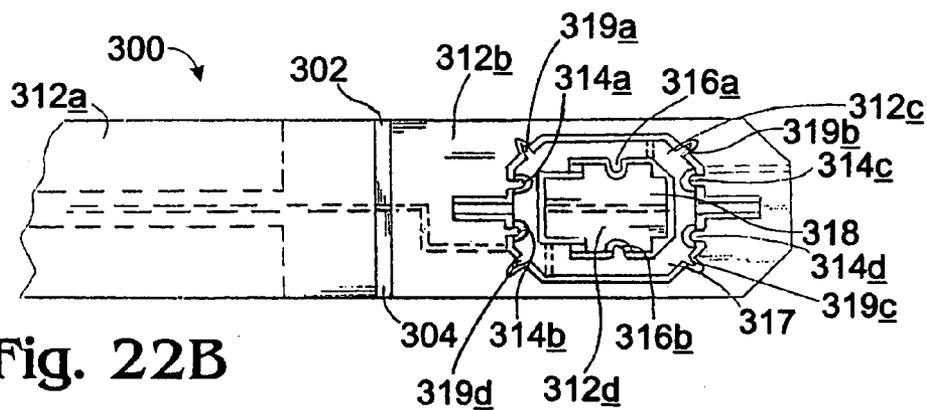


Fig. 22B

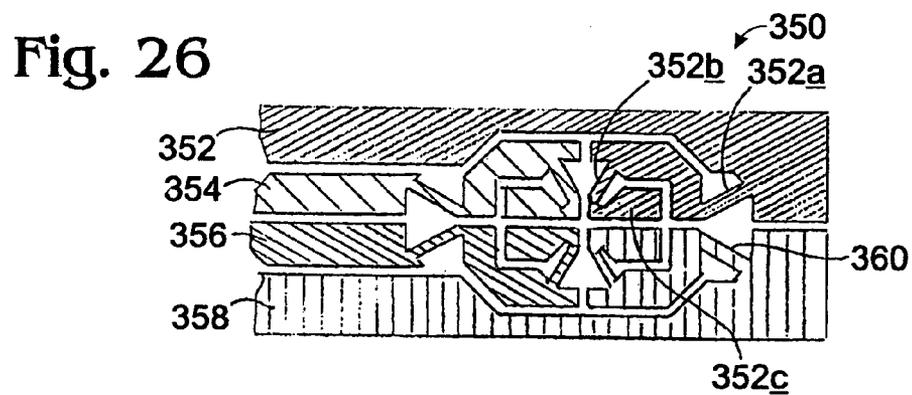
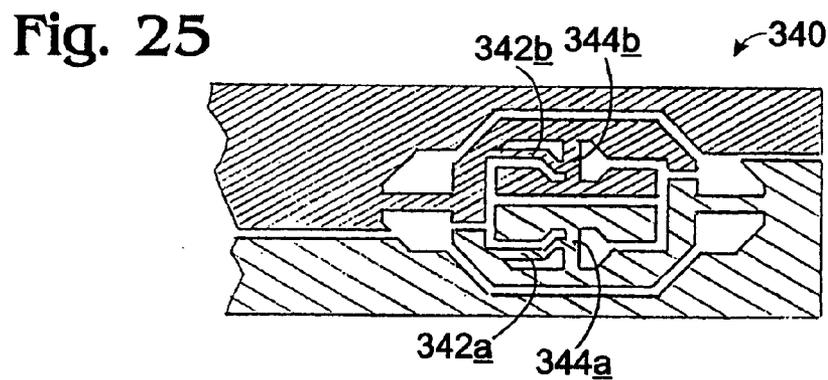
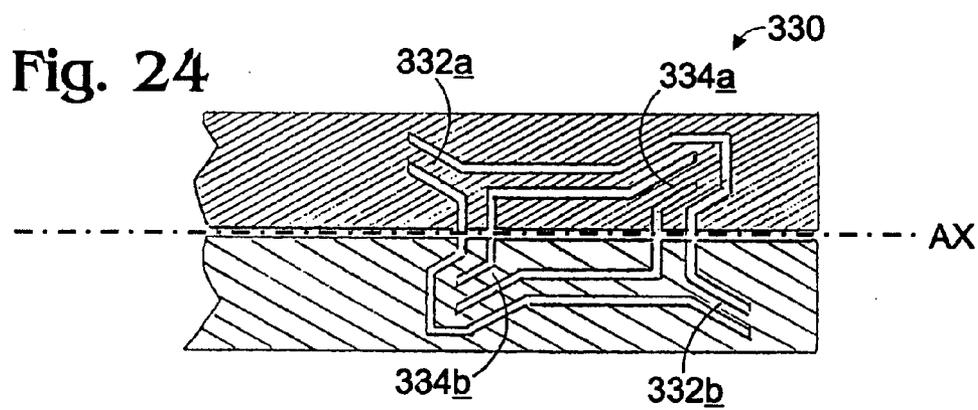
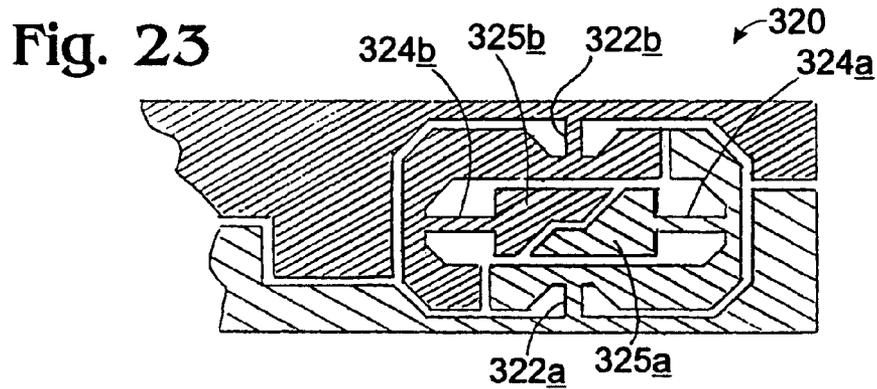


Fig. 27A

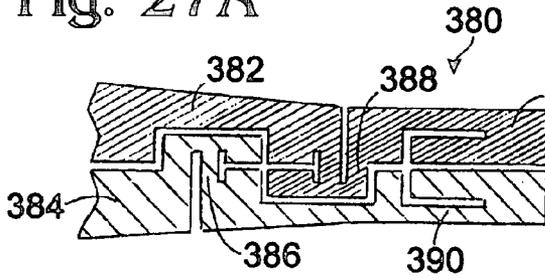


Fig. 27B

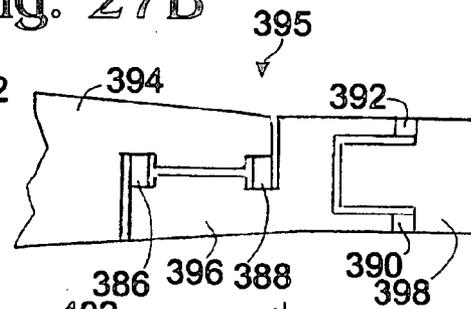


Fig. 28A

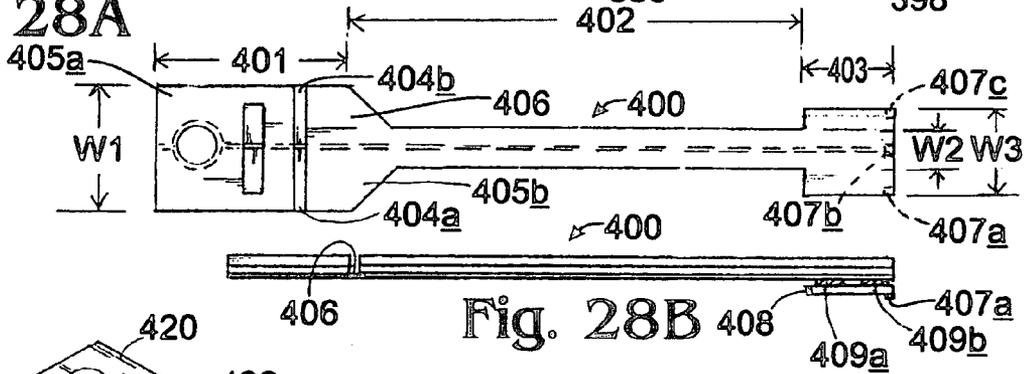


Fig. 28B

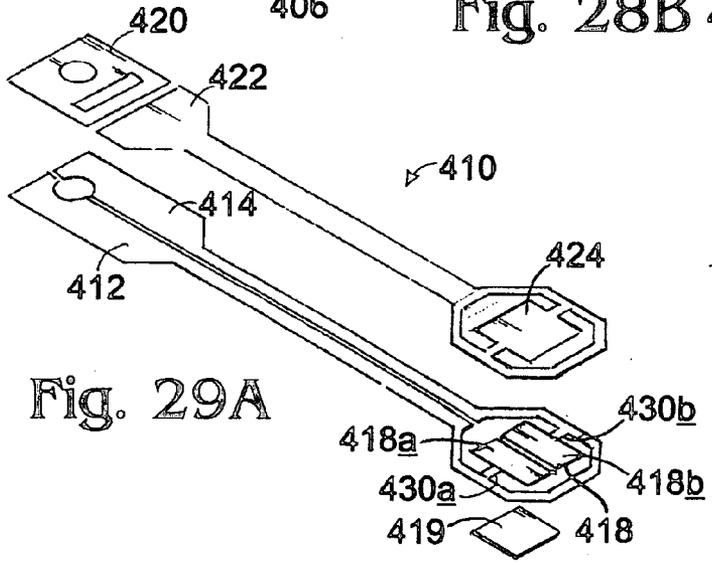


Fig. 29A

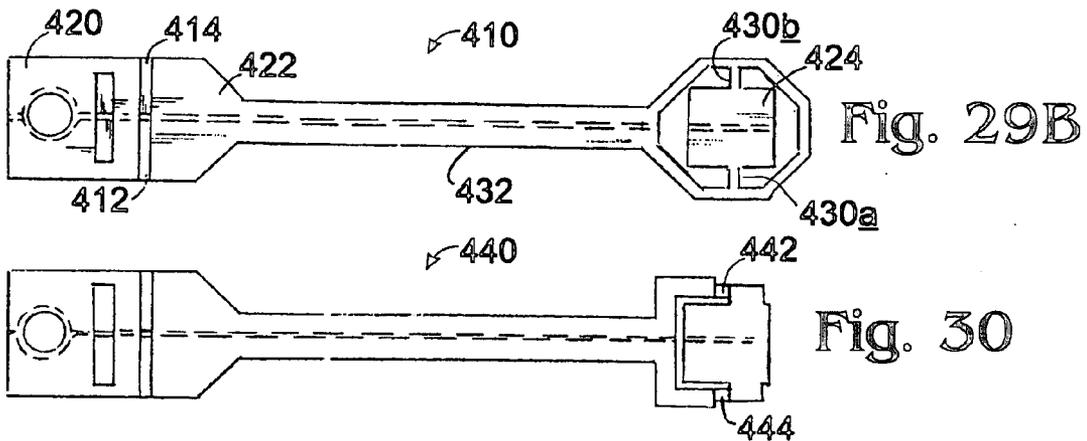


Fig. 29B

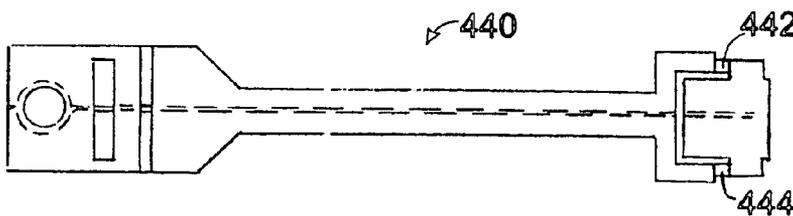
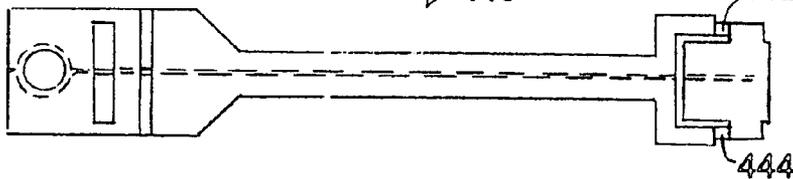


Fig. 30



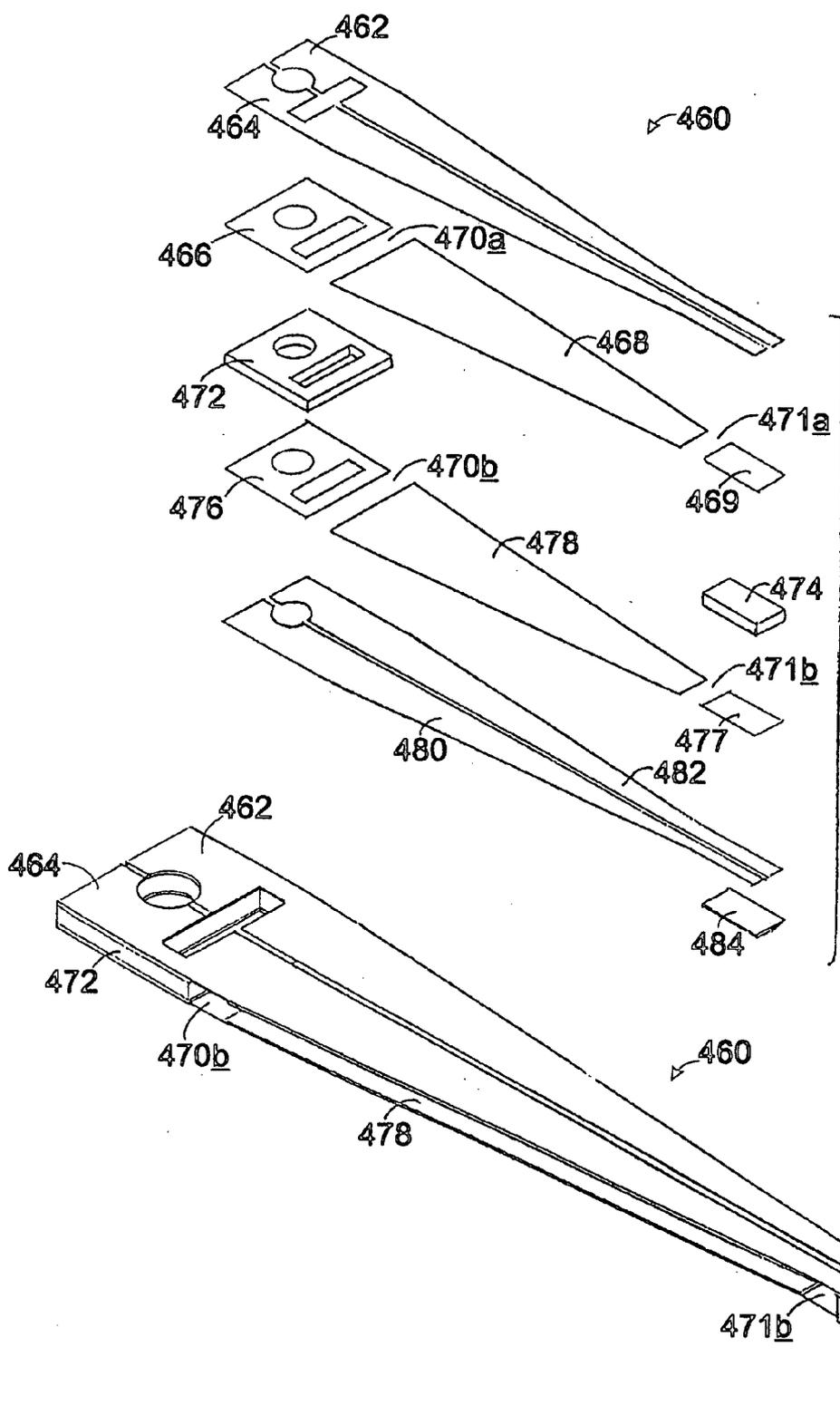


Fig. 31

Fig. 32

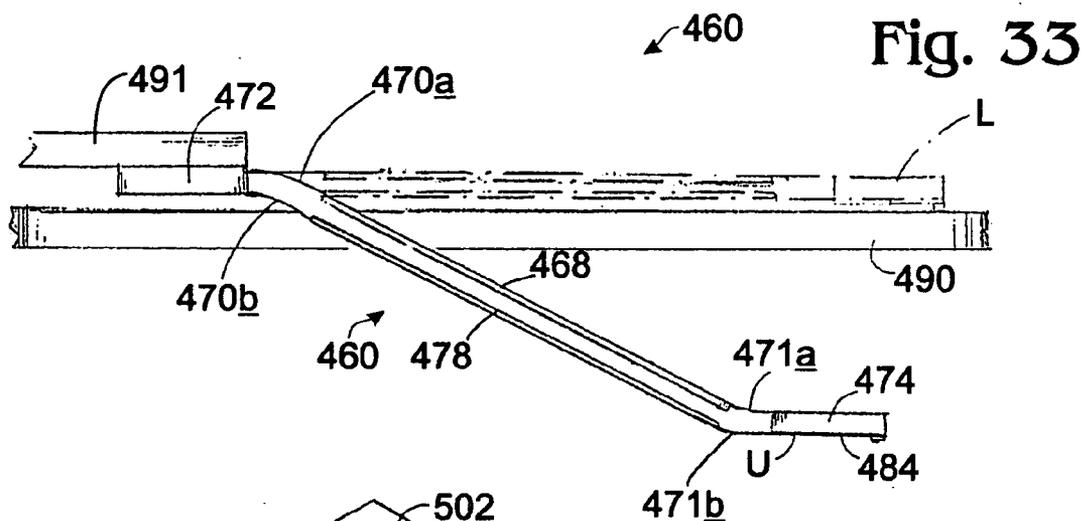


Fig. 33

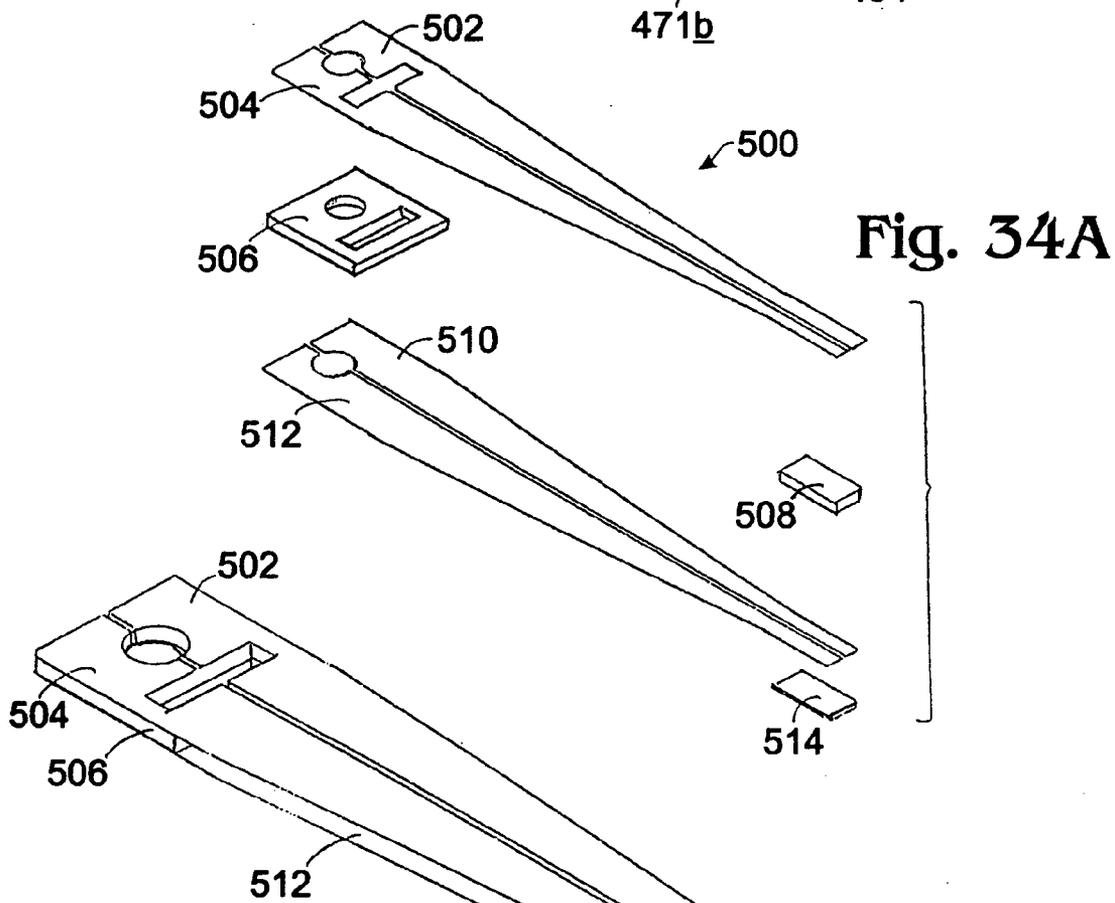


Fig. 34A

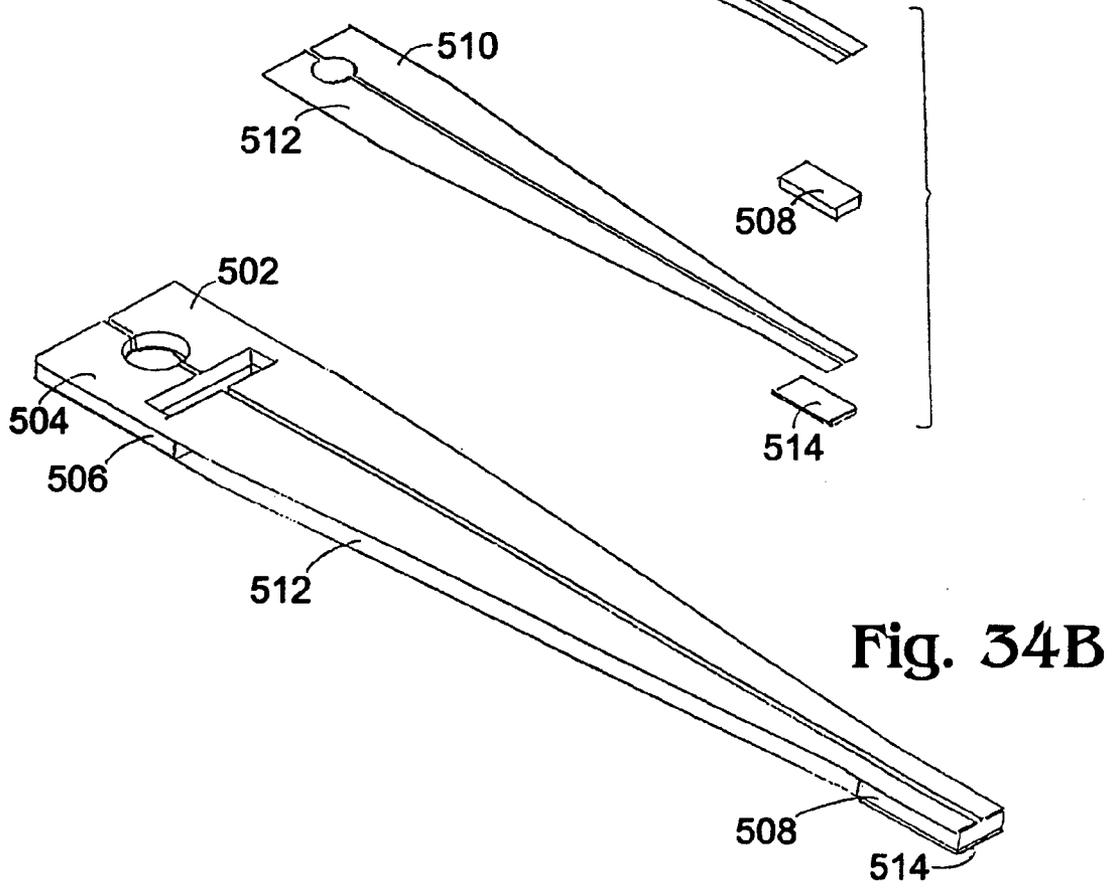


Fig. 34B

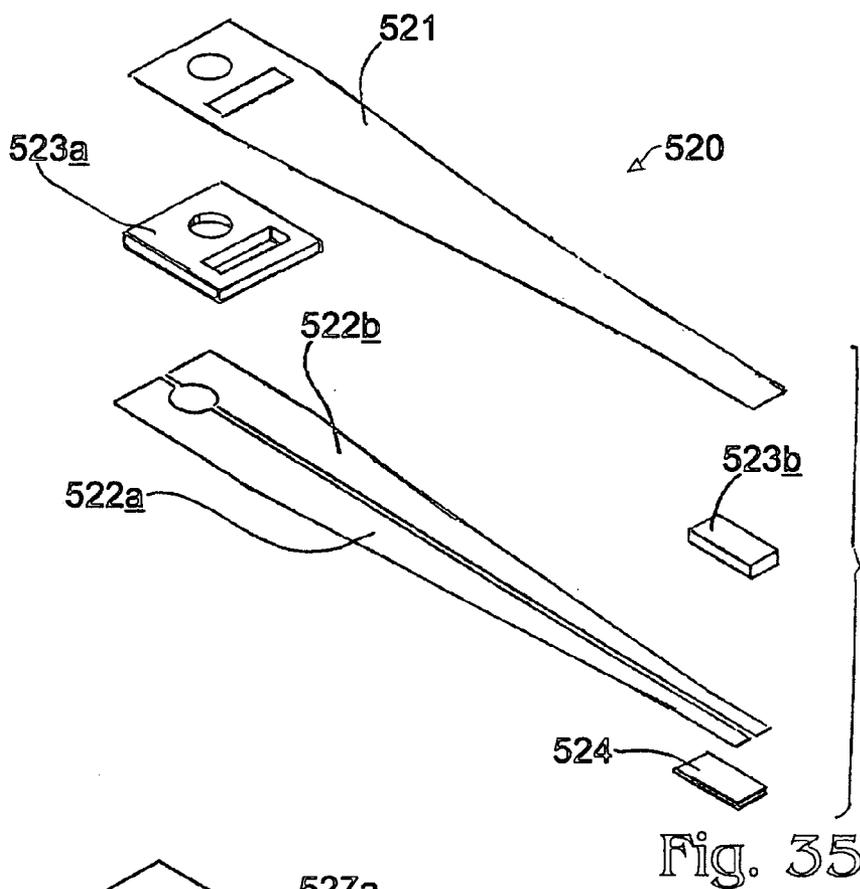


Fig. 35

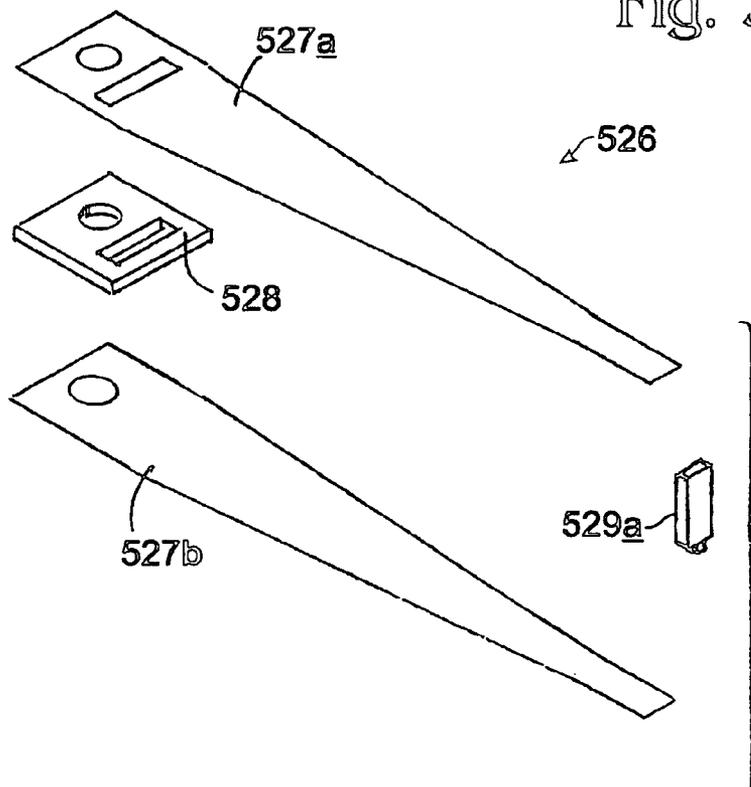


Fig. 36A

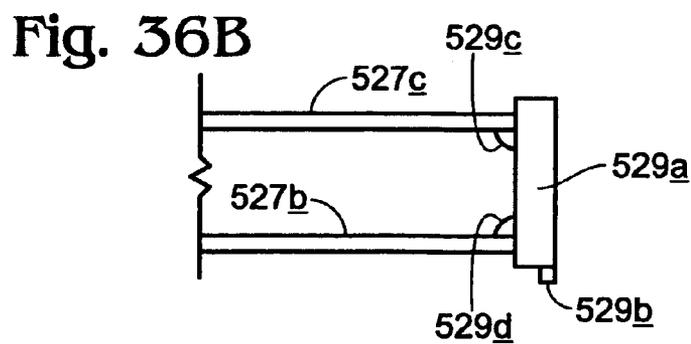
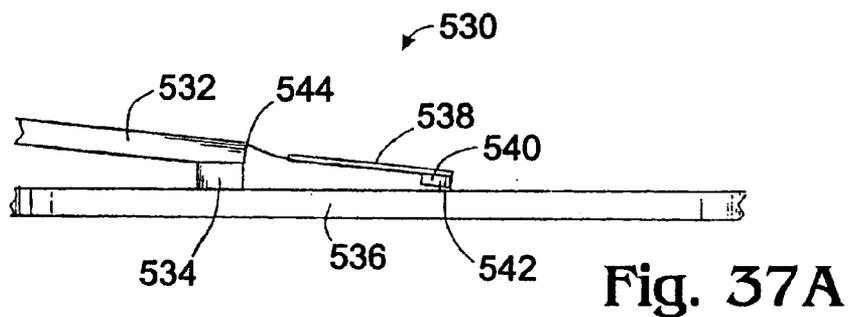
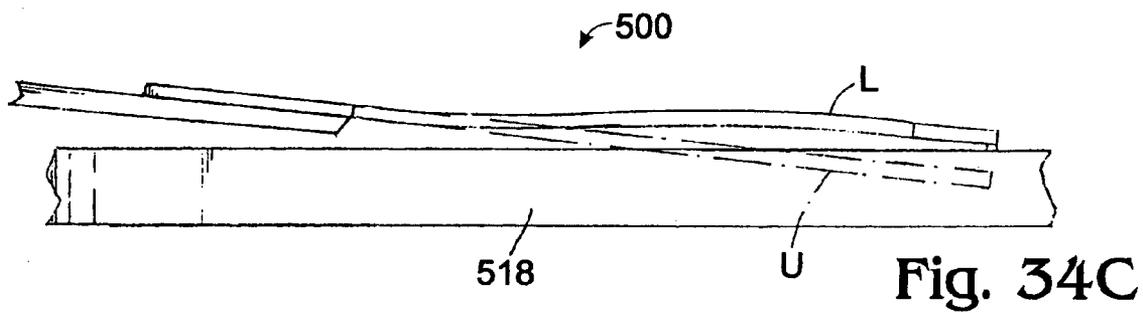


Fig. 37B

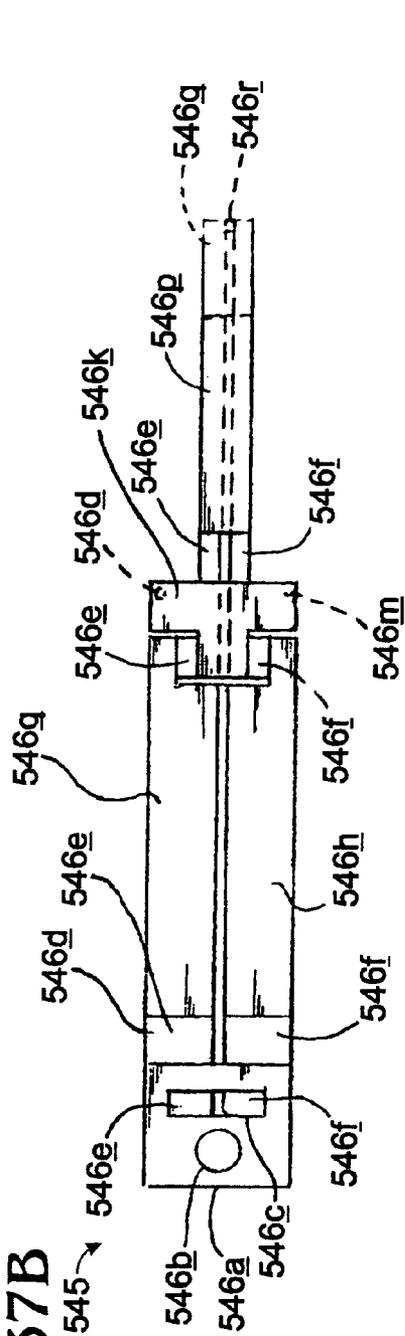
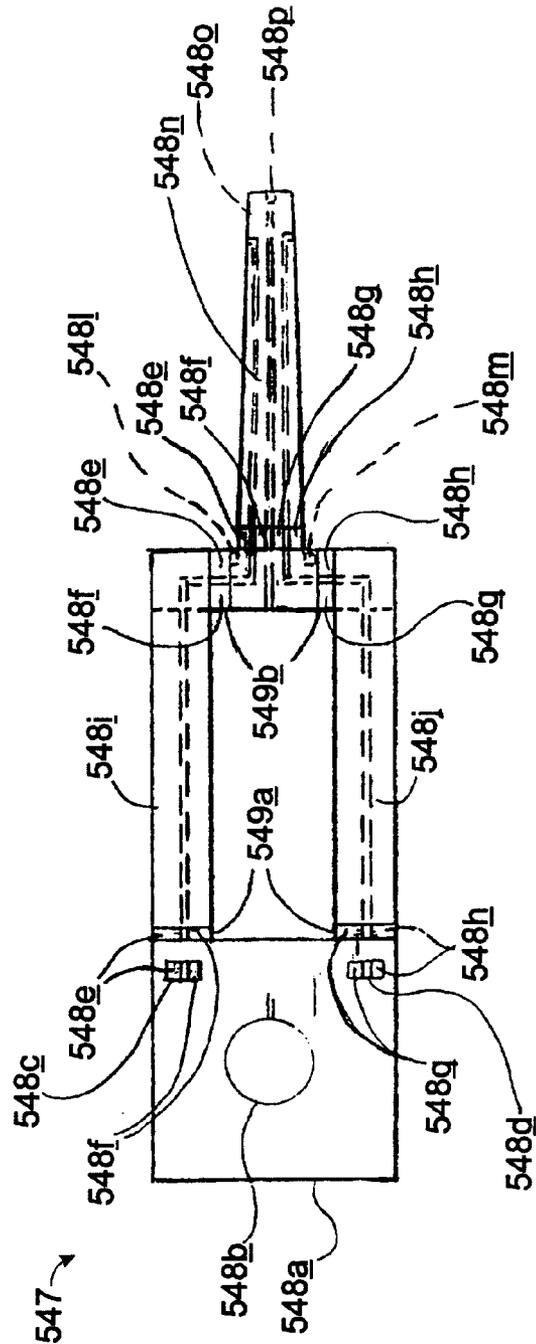


Fig. 37C



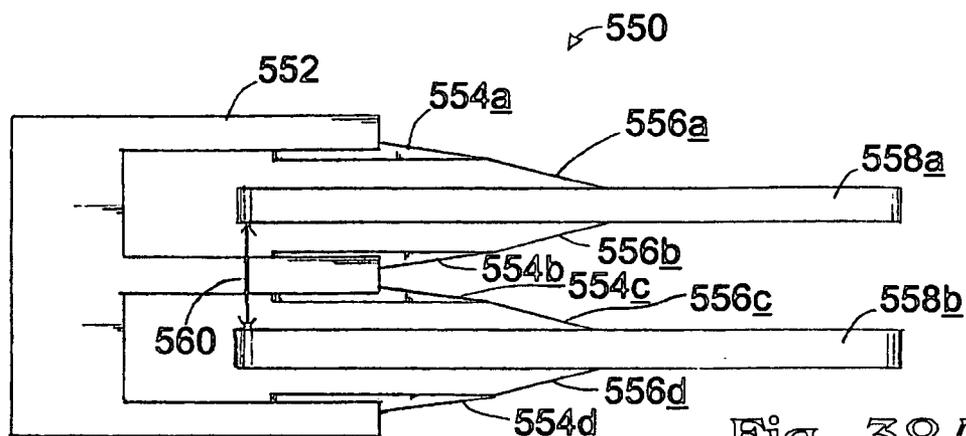


Fig. 38A

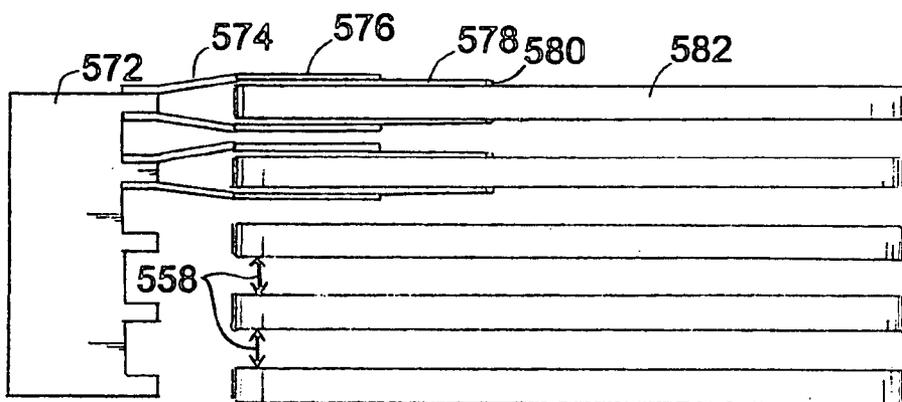


Fig. 38B

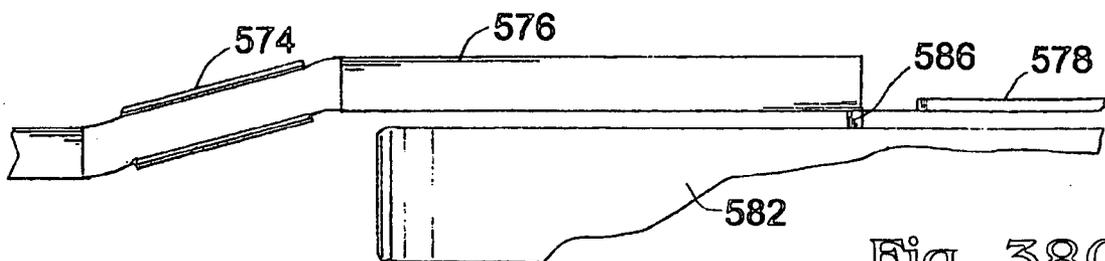


Fig. 38C

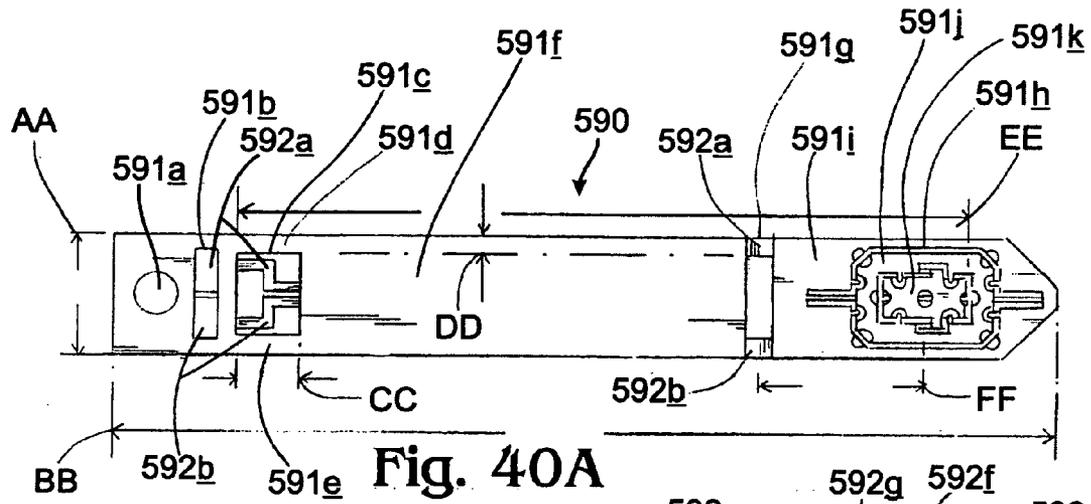


Fig. 40A

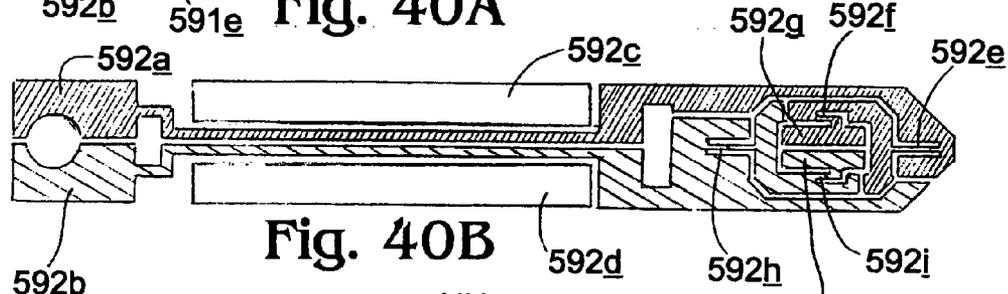


Fig. 40B

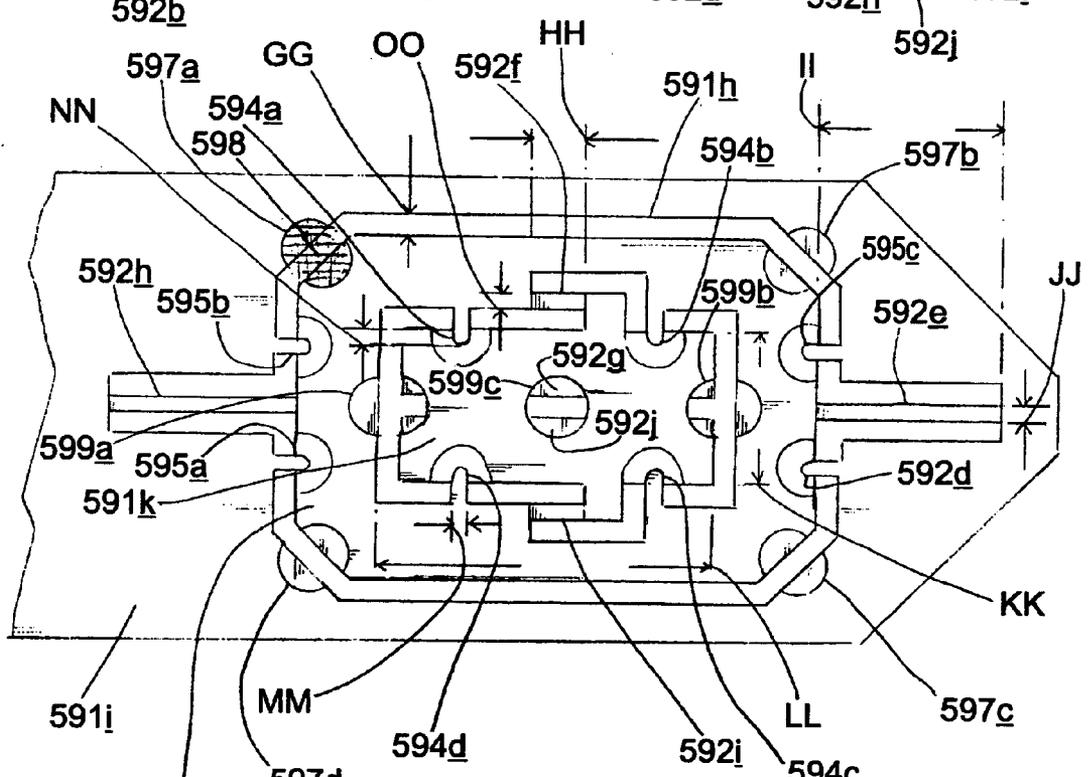


Fig. 40C

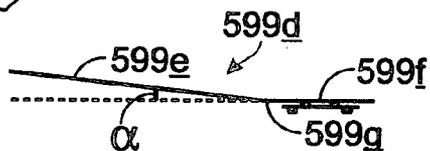
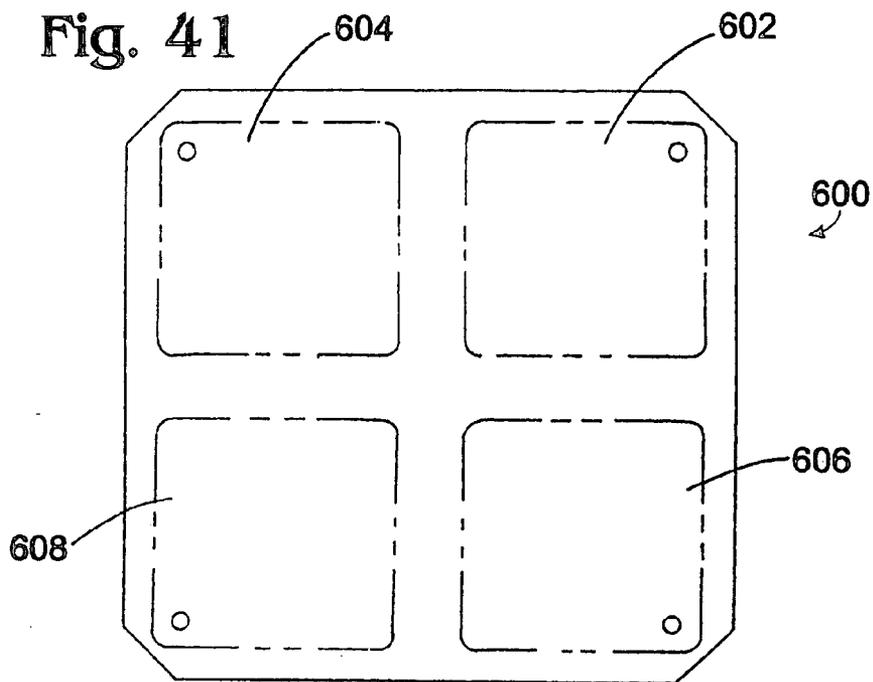


Fig. 42

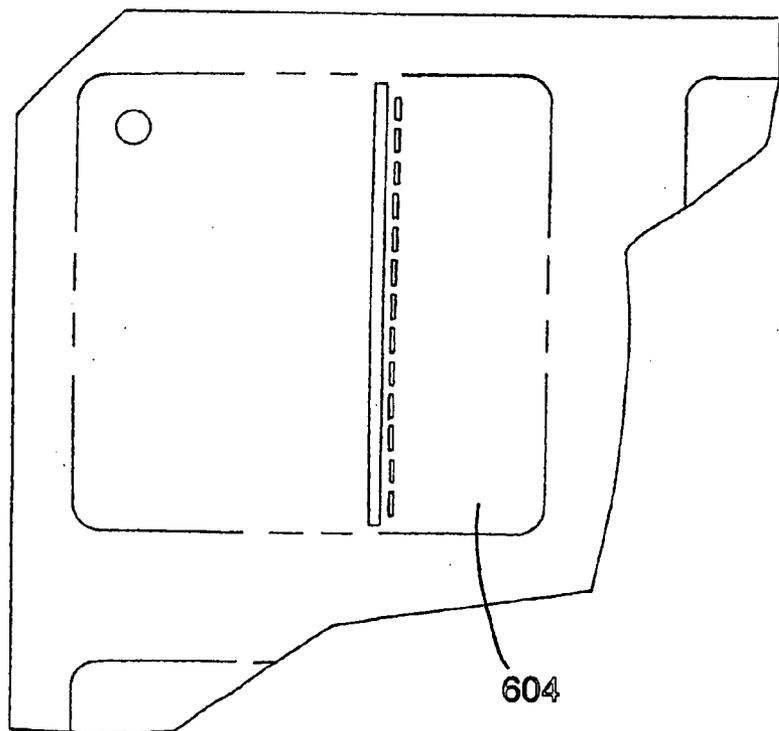


Fig. 40D

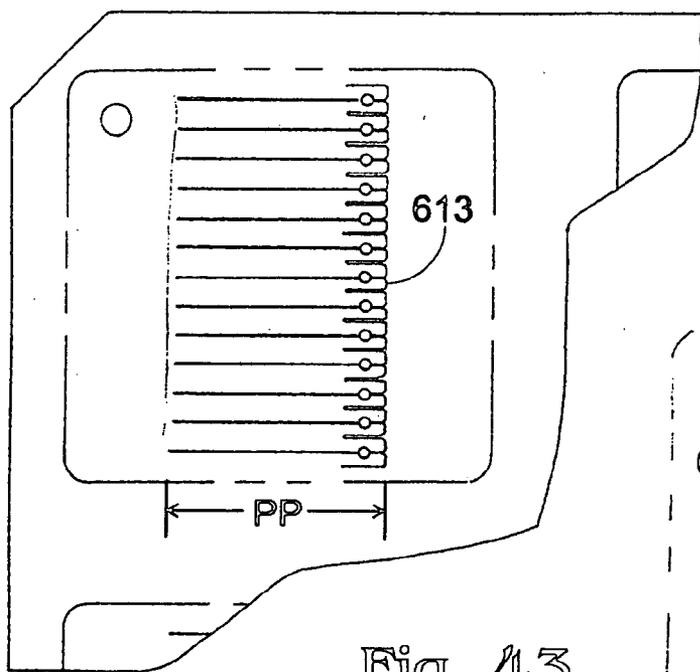


Fig. 43

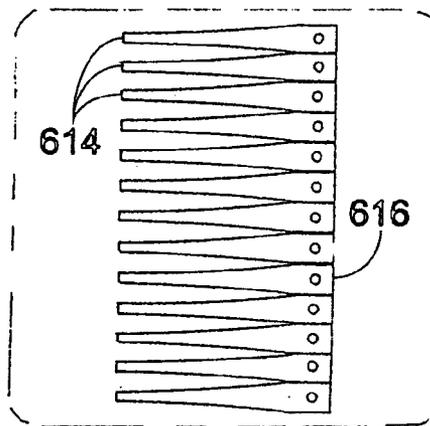


Fig. 44

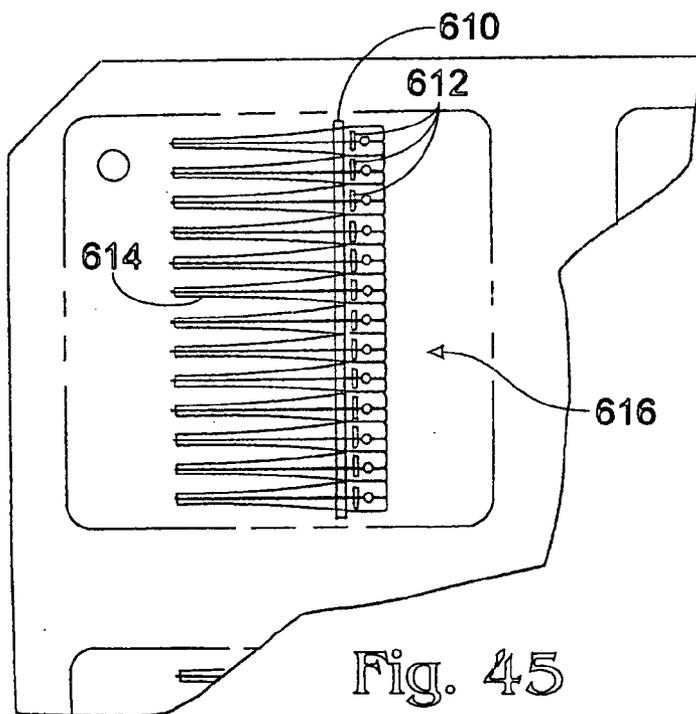


Fig. 45

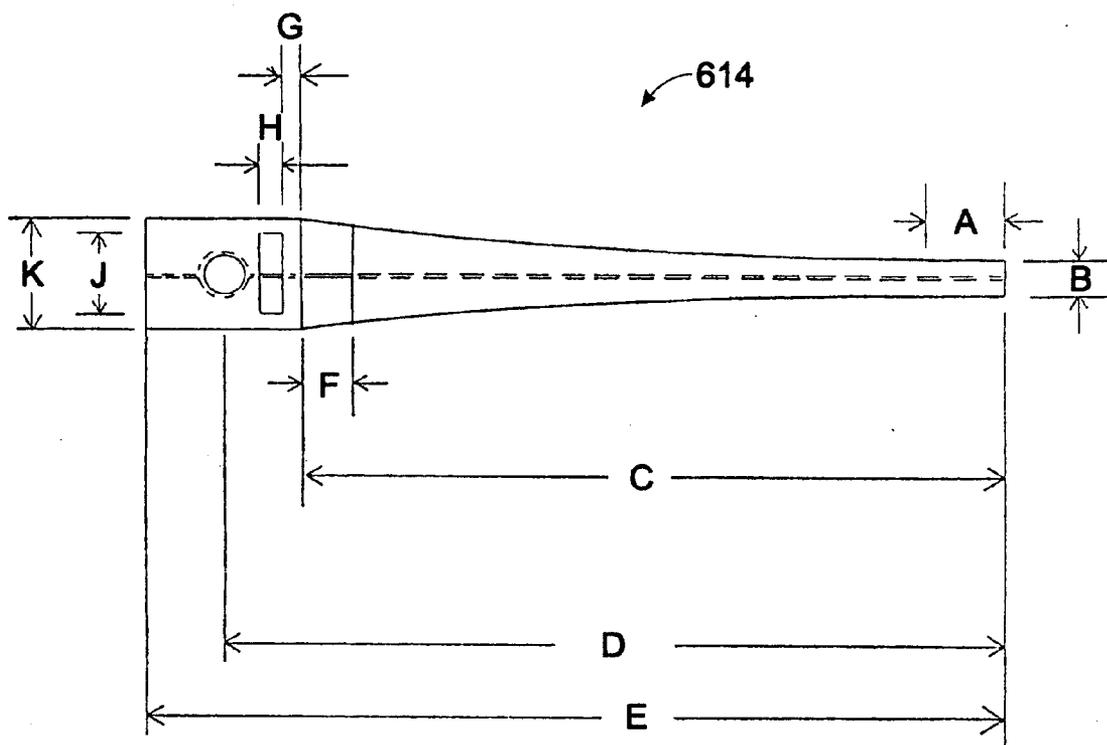


Fig. 46

Fig. 50A

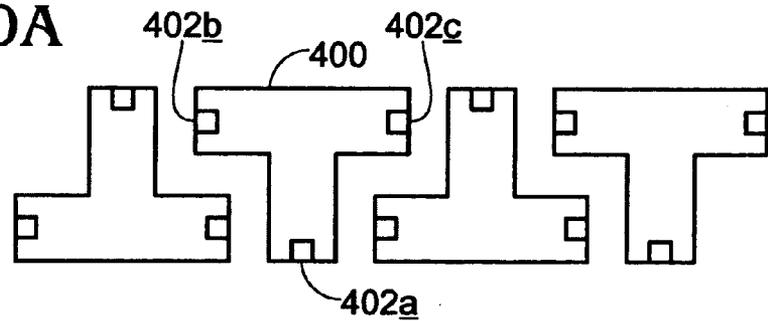


Fig. 50B

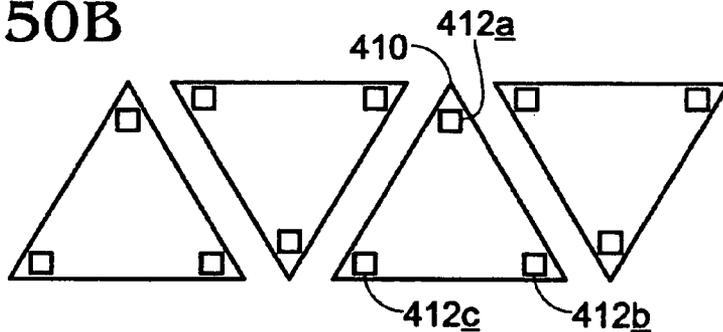


Fig. 47

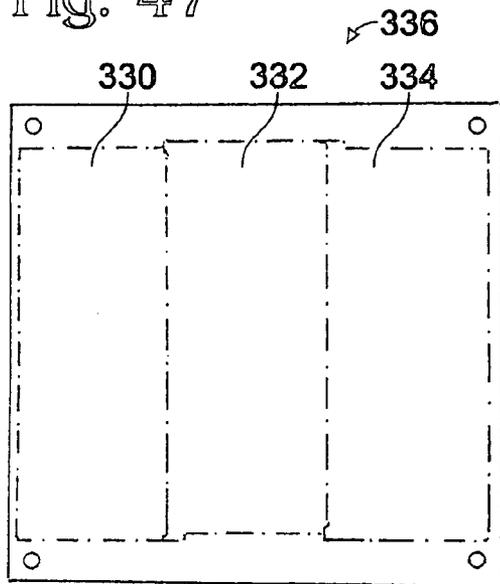


Fig. 49

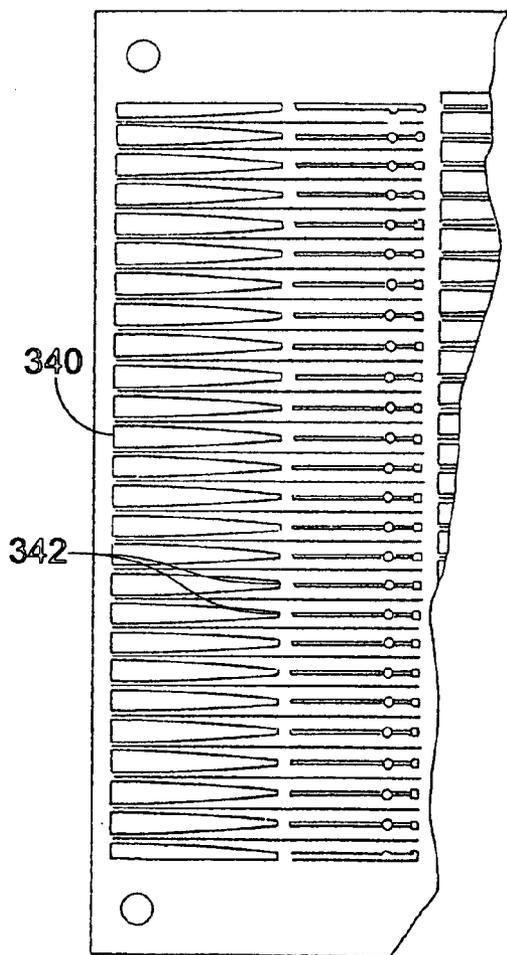
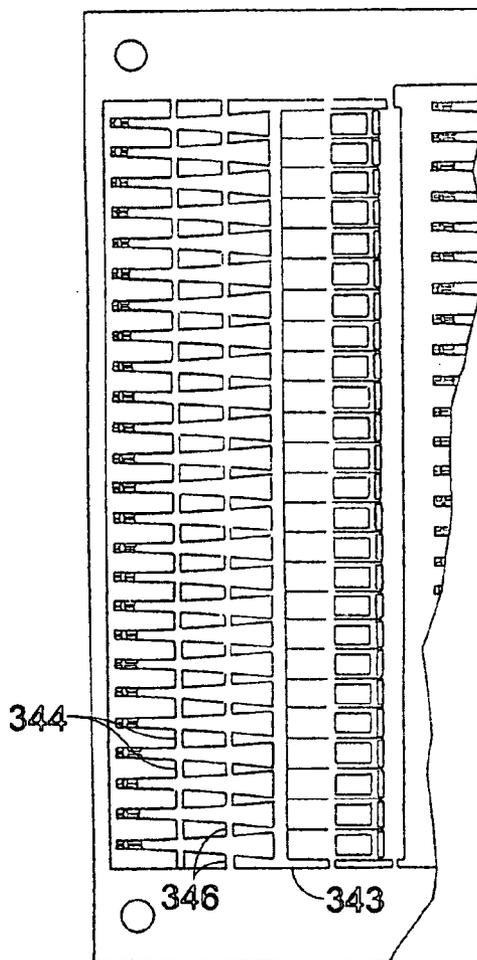


Fig. 48

**TRANSDUCER/FLEXURE/CONDUCTOR
STRUCTURE FOR ELECTROMAGNETIC
READ/WRITE SYSTEM**

**CROSS REFERENCE TO RELATED
APPLICATIONS**

[0001] This is a continuation application of U.S. patent application Ser. No. 08/338,394 which was filed on Nov. 14, 1994, which is a continuation-in-part of U.S. patent application Ser. No. 08/191,967 (now abandoned) which was filed on Feb. 4, 1994, which was a continuation-in-part of U.S. patent application Ser. No. 07/919,302 (now abandoned) which was filed on Jul. 23, 1992, which was a continuation-in-part of U.S. Pat. No. 5,174,012 which was filed on Dec. 12, 1991 and issued on Dec. 29, 1992, which was a continuation of U.S. Pat. No. 5,073,242 which was filed on Jul. 24, 1991 and issued on Dec. 17, 1991, which was a continuation of U.S. Pat. No. 5,041,932 which was filed on Nov. 27, 1989 and issued on Aug. 20, 1991. This is also a continuation-in-part of U.S. patent application Ser. No. 07/990,005 (now abandoned) filed Dec. 10, 1992 which is a continuation of U.S. patent application Ser. No. 07/746,916 (now abandoned) filed on Aug. 19, 1991. Additionally, this is a continuation-in-part of Ser. No. 07/966,095 now issued as U.S. Pat. No. 5,550,691, which was filed on Oct. 22, 1992 and issued on Aug. 27, 1996 which is a continuation-in-part of U.S. patent application Ser. No. 07/783,509 (now abandoned) filed Oct. 28, 1991. Further, this is a continuation-in-part of U.S. patent application Ser. No. 07/783,619 now issued as U.S. Pat. No. 5,490,027 filed on Oct. 28, 1991 and issued on Feb. 6, 1996. This is also a continuation-in-part of U.S. patent application Ser. No. 08/179,758 (now abandoned) filed on Jan. 7, 1994, which is a continuation of U.S. patent application Ser. No. 07/684,025 (now abandoned) filed on Apr. 10, 1991. This is also a continuation-in-part of U.S. patent application Ser. No. 08/017,984 (now abandoned) filed on Feb. 12, 1993, which is a continuation from U.S. patent application Ser. No. 07/770,593 (abandoned) filed on Oct. 3, 1991. This is also a continuation-in-part from U.S. patent application Ser. No. 08/180,540 (now abandoned) filed Jan. 12, 1994, which is a continuation-in-part from U.S. patent application Ser. No. 07/760,586 (now abandoned) filed Sep. 16, 1991. The following U.S. patent applications and patents are incorporated by reference into this application: application Ser. No. 07/911,680, U.S. Pat. No. 5,041,932, application Ser. No. 07/990,005, application Ser. No. 07/746,916, application Ser. No. 07/966,095, U.S. Pat. No. 5,550,691, application Ser. No. 07/783,509, application Ser. No. 07/783,619, U.S. Pat. No. 5,490,027, application Ser. No. 08/179,758, application Ser. No. 07/684,025, application Ser. No. 08/017,984, and application Ser. No. 07/770,593.

FIELD OF INVENTION

[0002] The present invention relates to electromagnetic read/write, information storage and retrieval systems, and in particular, to the structural merging in such systems of electrical and mechanical functionality, and to ancillary matters that surface as structural, organizational opportunities as a result of such merging. Recognizing that the various features of the invention can have important applicability in a wide range of kinds of such systems (e.g., rigid-disk, floppy-disk, drum, tape, etc. systems), the description which

follows herein focuses attention on rigid-disk systems—an arena which is most central in today's commercial applications. Accordingly, specification and claim references made herein to rigid disks should be read to include these other-kinds-of-media systems.

[0003] Given the merged-functionality aspect of the present invention, many features thereof, accordingly, focus upon improvements in mechanical load-bearing and in motion-articulating characteristics of transducers, and of flexures which carry such transducers, that are used in these kinds of systems. In this context, the field of the invention encompasses systems wherein (a) a read/write transducer flies over a media recording surface, (b) such a transducer is intended for contact-capable operation, and operates with intermittent media-surface contact, and (c) such a transducer is intended for contact-capable operation, and operates in substantially continuous contact with a media recording surface.

**BACKGROUND AND SUMMARY OF THE
INVENTION**

[0004] In the march of progress which has characterized ongoing development of disk-drive, electromagnetic read/write systems, the quests for enlargement of areal recording density, and for improved-quality read/write signal communication between a disk's recording surface and a transducer, have been high on the list of technical interest and relentless pursuit. This situation has been reflected, inter alia, in significant reductions in components' sizes and masses, by reductions in the "effective masses" of those components which react dynamically during read/write operations, and in dramatic reduction in the separation which exists between the working read/write zone of a transducer and a disk's recording surface. These advances include, according to an important line of development by the Censtor Corporation of San Jose, Calif., system embodiments in which a read/write transducer operates in substantially continuous sliding contact with such a recording surface. The latter line of advancement in the art of disk-drive recording is well illustrated and expressed in the parent patent and patent applications which have been set forth hereinabove.

[0005] Pausing for a moment at this point to focus upon prior art efforts by others to bring about size reductions, it is important to bear in mind that these prior art changes have, by and large, been accomplished with what might be thought of as a segregated rather than a merged focus upon the three core functionalities—electrical, mechanical and magnetic—of read/write transducers and supporting flexures. In other words, prior art thinking has looked upon the respective components in this environment which offer each of the individual functionalities as being essentially independent of the other-functionality components. As a consequence, there has been somewhat of a naturally perceived limit in how far one can go to bring about significant size reduction—a limit dictated by functional performance constraints, and even more appreciably, probably, by manufacturing-costs and manufacturing-capabilities constraints.

[0006] Specifically, and looking for a moment just at the issue of mechanical load bearing, prior art thinking has been based upon the notion that once necessary mechanical load-bearing requirements are known, all of that structure which has been looked upon in the past as being the sole

constituent attending to that functionality can only be reduced in size just so much if it is to remain practically manufacturable. However, beginning with the work of Hal Hamilton as such is expressed in the above-referred-to '932 patent, a new kind of thinking has entered this art, whereby "merger of functionality" is viewed as providing an opportunity for retaining all necessary electrical, mechanical and magnetic capability, while at the same time allowing for substantial shrinking of overall size, and actual improvement in practical manufacturability. More particularly, in the Hamilton '932 disclosure, there surfaces a recognition that electrical current-carrying structure can be utilized significantly to carry mechanical load, and conversely, that mechanical load-bearing structure can be utilized significantly to carry electrical current. In other words, what might be thought of as singular-character structure, or material, functions in multiple ways. Not only does this unique way of thinking about merged-functionality yield surprising size- and mass-reduction opportunities, but also it tends to lead toward structures which are inherently simpler in form and in construction, and less complex and costly to fabricate.

[0007] It is this "merged-functionality" view which underlies key contributions made to the art by the present invention.

[0008] Continuing, and directing attention to other matters upon which this invention is focussed, in the ever more intimate environment of the interface between a disk's recording surface and a read/write transducer, and in addition to the size, mass, effective mass and spacing issues just generally expressed, many other considerations sit as important participants at the table of key technical concerns. For example, tight control over, and maintenance of, a very precise XYZ spatial location of a transducer in relation to a disk surface is critical, as is the ability of the transducer and supporting flexure structure to respond rapidly and fluidly to disk-surface topographical features, and/or to other things and events which require speedy, accommodating, operating-attitude adjustment. This kind of adjustment must take place in a manner minimizing as much as possible any occasions of signal-communication drop-out, and in a manner free of disruptive resonance vibrations. Attention also must be addressed to damping and shock-absorbing issues.

[0009] All of these considerations need to be taken into account as well (a) in systems where a transducer flies over a disk's recording surface, (b) in systems where contact operation occurs (intermittently or continuously), and (c) in systems which, on the one hand, have gimballed transducer structures, and on the other hand, non-gimballed transducer structures.

[0010] In the gimballed transducer setting, the merged functionality focus aspect of the invention opens the door to the fabrication and use of a load-bearing transducer chip which has a substantially planar body, with plural, projecting disk-surface contact feet, or pads, and which can operate, relative to a disk's recording surface, with substantially a zero-angle-of-attack, and with the read/write portion of the transducer in intimate contact with that surface. This, in turn, offers the opportunity for electromagnetic design which occupies space in the plane of the body, and which allows for placement of the read/write zone anywhere relative to that body.

[0011] Given the above remarks and comments, it is an important object of the present invention to offer transducer/

flexure improvements along the lines just suggested—focused on the notion of structural merging, for example, of electrical and mechanical functionality.

[0012] A related object of the invention is to provide such improvements which lead toward simple, low-cost, low-mass structures that offer the opportunity for appreciable enlargement in areal density of recorded information, with reliable and improved signal-communication characteristics.

[0013] Thus, an important object is to provide a head/flexure structure which includes load-bearing (merged-functionality) conductors.

[0014] A related object is to provide a head/flexure structure in which the conductors perform mechanical functions in addition to their function of conducting electrical signals between a head and other circuitry.

[0015] Still another object of the invention disclosed herein is to provide a flexure/conductor structure which supports a head in a precise location and orientation relative to the surface of a medium.

[0016] Yet a further invention object is for the head-supporting flexure to be capable of supporting the head in a contacting relationship with the disk while reading or writing, without the occurrence of catastrophic head crash events or excessive interface wear.

[0017] Also, an object of the invention is to provide a flexure/conductor structure which is capable of moving, the head along a Z-axis, i.e., that axis which is normal to the surface of the disk, with a minimal degree of angular rotation, i.e., minimizing the angular constant.

[0018] Another object is to provide a flexure/conductor structure which exhibits maximum levels of lateral and torsional resonant frequencies with the minimal amount of gain.

[0019] Still a further object is to provide a transducer/flexure/conductor structure which has a minimal number of parts, and which can be produced by a relatively straightforward and cost-effective process, including, in certain cases, an automated assembly process.

[0020] Another object is to provide a flexure/conductor structure which is capable of compensating for topographical irregularities in the surface of the recording medium.

[0021] Yet another object of the invention is to provide a flexure/conductor structure in which the head is allowed a certain range of pitch and roll movement independent from the flexure.

[0022] A further object is to provide a head/flexure structure which has a tunable hinge near its proximal end.

[0023] Other objects include providing a head/flexure structure which: (a) is wireless; (b) is amenable to compact disk-to-disk stacking; and (c) contains more than one pair of conductors.

[0024] Still a further object is to provide a head/flexure structure which has a gimbal including conductive articulators.

[0025] Thus, the inventive subject matter presented herein regards improvements in transducer/flexure structure for an electromagnetic read/write system, and relates, inter alia, to

structures, such as flexures, for carrying electromagnetic read/write transducers, and more particularly, to such structures wherein electrical conductors which connect with such transducers are utilized significantly, in an augmentive way, as mechanical load-bearing and articulating elements in the structures. The subject matter of the invention also relates to contact-capable read/write systems in which the read/write transducer acts directly as a load-bearing structure under disk-contact conditions. According to an important aspect of the invention, therefore, such augmented-role conductors play the dual roles of (a) conducting electrical signals between a transducer and remote, external circuitry, such as a signal processor, and (b) at the same time supporting mechanical load (such as a bending and/or articulating load), including, in certain embodiments, 100% of that load in a certain portion or region of a transducer-carrying structure.

[0026] Fundamentally, the subject matter of the present invention rests on several key concepts, some of which spring from the notion that innovation in the load-carrying/articulation characteristics of transducer-carrying structure can significantly enhance overall read/write system performance. One of these concepts—based upon a new and striking “merged-functionality” recognition—is that the very same conductors which carry signal-bearing information to and from a read/write transducer can also function mechanically as the articulating and load-bearing beam structure which carries and supports such a transducer, statically and dynamically, for instance, in the setting of a cantilever-type support arrangement for a disk read/write transducer. This conceptual thought carries also into an arrangement where, effectively, the transducer is supported for gimbaling action, with the recognition that what might be thought of as the gimbaling articulators (hinges or torsional beams) can be formed by electrical-current-carrying conductors.

[0027] Another foundation concept is that the flexure/beam transducer-carrying construction can take important advantage of what can be viewed as bilateral motion independence, wherein a pair of spaced beam components afford a single- or dual-axis articulation capability to a supported transducer. Indeed, such construction can enable dual-degree-of-motion gimbaling action (as just suggested above) for such a transducer. The shift of mechanical articulation and load-bearing responsibilities to signal-carrying conductors is an especially useful concept in so-called micro-flexure designs where extremely small mechanical structures are involved.

[0028] A further important concept is that a read/write transducer can itself be utilized as a load-bearing structure—a concept leading, *inter alia*, toward minimizing of the size and mass of the overall transducer/flexure/conductor structure.

[0029] In addition to the structural contributions made by the present inventive subject matter, also furnished thereby are novel methods of producing micro-transducer-support structures employing signal-carrying conductors as mechanical load-bearing/articulating elements such, for example, as hinges, torsional beams, etc.

[0030] These and other objects, advantages and features that are offered by the present invention will become more fully apparent as the description which now follows is read in conjunction with the accompanying drawings.

DESCRIPTION OF THE DRAWINGS

[0031] **FIGS. 1A and 1B** are views of a transducer/flexure which is disclosed and claimed in U.S. Pat. No. 5,041,932. **FIG. 1A** is a side view of the transducer/flexure, loaded on a disk, in relation to an XYZ coordinate system. **FIG. 1B** is a cross-sectional view of the flexure shown in **FIG. 1A**, with this view being taken generally along line 1B-1B in **FIG. 1A**.

[0032] **FIG. 2** is an exploded perspective view of a tapered transducer/flexure structure with load-bearing conductors and a hinge.

[0033] **FIG. 3A** is a top view of the transducer/flexure shown in **FIG. 2**.

[0034] **FIG. 3B** is a partial side view of the distal end of the transducer/flexure shown in **FIG. 3A**.

[0035] **FIG. 3C** is a bottom view of the transducer chip shown in **FIG. 3B**.

[0036] **FIG. 3D** is an enlarged, fragmentary view of the area in **FIG. 3B** embraced by curved arrows 3D-3D, illustrating a modified form of transducer pole and coil structure.

[0037] **FIG. 4** is a partial top view of a flexure, focusing on the hinge region.

[0038] **FIG. 5A** is a cross-sectional view of the flexure shown in **FIG. 3A**.

[0039] **FIGS. 5B and 5C** are cross-sectional views of flexures with load-bearing conductors and additional damping and constraining layers.

[0040] **FIG. 6** is a partial side view of the flexure shown in **FIG. 3A**, focusing on the hinge region.

[0041] **FIG. 7** is a schematic partial view of a flexed beam with an intervening adhesive resin layer.

[0042] **FIG. 8** is an exploded perspective view of a transducer/flexure with four conductors, and a hinge near the proximal end of the flexure.

[0043] **FIG. 9** is a top view of the transducer/flexure shown in **FIG. 8**, assembled. Conductor boundaries, which are covered by stiffeners, are indicated by dashed lines.

[0044] **FIG. 10** is an exploded perspective view of a transducer/flexure with load-bearing conductors and a load-button gimbal.

[0045] **FIG. 11** is a perspective view of the transducer/flexure shown in **FIG. 10**, assembled except for mounting of the chip (transducer).

[0046] **FIG. 12A** is a top view of the transducer/flexure shown in **FIGS. 10 and 11**. Conductor boundaries, which are covered by stiffeners, are indicated by dashed lines.

[0047] **FIG. 12B** is a partial side view of the distal end of the flexure shown in **FIG. 12A**.

[0048] **FIG. 12C** is a bottom view of the transducer shown in **FIG. 12B**.

[0049] **FIG. 13** is an exploded perspective view of a transducer/flexure with load-bearing conductors, a hinge near the proximal end of the flexure and a gimbal near the distal end of the flexure.

[0050] FIG. 14 is a partial top view of the conductors shown in FIG. 13, focusing on the distal ends of the conductors, specifically, the conductor gimbaling structure.

[0051] FIG. 15A is a top view of the transducer/flexure shown in FIG. 13, assembled.

[0052] FIG. 15B is a partial side view of the transducer/flexure shown in FIG. 15A.

[0053] FIG. 15C is a bottom view of the transducer shown in FIG. 15B.

[0054] FIG. 15D is a partial side view of the distal end of a gimbaled transducer/flexure with a modified transducer and pad configuration.

[0055] FIG. 15E is a bottom view of the transducer shown in FIG. 15D.

[0056] FIG. 16 is a thin-layer sectional view of the flexure shown in FIG. 15A.

[0057] FIG. 17A is a partial top view of the distal end of the transducer/flexure shown in FIG. 15A, with the addition of a membrane damping layer in the vicinity of the gimbal.

[0058] FIG. 17B is the same as FIG. 17A except the damping layer is localized over four discrete regions of the gimbal.

[0059] FIG. 18 is a partial top view of the distal end of a transducer/flexure with a membrane which functions primarily as a gimbal structure.

[0060] FIG. 19A is a top view of a transducer/flexure with load-bearing conductors, two hinges and a modified gimbal.

[0061] FIG. 19B is a partial top view of the distal ends of the conductors in the transducer/flexure shown in FIG. 19A.

[0062] FIG. 20 is a side view of the transducer/flexure shown in FIG. 19A, operating on a disk.

[0063] FIG. 21 is a top view of a transducer/flexure, similar to the one shown in FIG. 19A, except that conductor dimensions are modified.

[0064] FIG. 22A is a side view of the transducer/flexure shown in FIG. 21, with a pre-bend near the proximal end of the flexure. The flexure is shown in its pre-loaded position (solid lines) and in its operating or loaded position (dash-dot lines).

[0065] FIG. 22B is a partial top view of a flexure which is similar to the flexure shown in FIG. 21, except that it employs a modified gimbal.

[0066] FIGS. 23-25 are top views of modified two-conductor gimbaling structures.

[0067] FIG. 26 is a top view of a modified four-conductor gimbaling structure.

[0068] FIG. 27A is a partial top view of a two-conductor gimbaling structure that forms part of a transducer/flexure which employs hinges to allow roll and pitch movement of the chip.

[0069] FIG. 27B is a partial top view of the gimbaling structure shown in FIG. 27A, with the addition of stiffening layers.

[0070] FIG. 28A is a top view of a first embodiment of a torsionally compliant transducer/flexure.

[0071] FIG. 28B is a side view of the transducer/flexure shown in FIG. 28A.

[0072] FIG. 29A is an exploded perspective view of a second embodiment of a torsionally compliant transducer/flexure, with a pitch gimbal mechanism.

[0073] FIG. 29B is a top view of the transducer/flexure shown in FIG. 29A.

[0074] FIG. 30 is a top view of a third embodiment of a torsionally compliant transducer/flexure with a pitch gimbal.

[0075] FIG. 31 is an exploded perspective view of a dual-cantilever transducer/flexure with four conductors and four hinges.

[0076] FIG. 32 is a perspective view of the transducer/flexure shown in FIG. 31, assembled.

[0077] FIG. 33 is a side view of the transducer/flexure shown in FIGS. 31 and 32. The flexure is shown in its pre-bent unloaded position (solid lines), and in its loaded or operating position (dash-dot lines).

[0078] FIG. 34A is an exploded perspective view of another dual-cantilever transducer/flexure.

[0079] FIG. 34B illustrates the transducer/flexure of FIG. 34A, assembled.

[0080] FIG. 34C is a schematic side view of the transducer/flexure shown in FIGS. 34A and 34B, in its unloaded position (dash-dot lines) and operating position (solid lines).

[0081] FIG. 35 is an exploded perspective view of another transducer/flexure embodiment.

[0082] FIG. 36A is an exploded perspective view of still another dual-cantilever transducer/flexure embodiment.

[0083] FIG. 36B is a partial side view of the distal end of the transducer/flexure shown in FIG. 36A.

[0084] FIG. 37A is a schematic side view of a disk-contacting mount configuration supporting a transducer/flexure in its operating position.

[0085] Each of FIGS. 37B and 37C is a top view of a transducer/flexure of the present invention including an alternative gimbal design.

[0086] FIG. 38A is a schematic side view of a flexure mounting system showing disk-to-disk spacing with respect to an E-block and mounted flexures.

[0087] FIG. 38B is a schematic side view of a modified flexure mounting system employing dual-cantilevers to permit closer disk-to-disk spacing.

[0088] FIG. 38C is a partial side close-up view of one of the flexures and dual-cantilever mount structures shown in FIG. 38B.

[0089] FIG. 39A is a schematic top view of a transducer/flexure mounted on a nut plate and including a two-conductor configuration with versatile, redundant connective tabs on opposite sides with the proximal end of the flexure/nut-plate structure.

[0090] FIG. 39B is a schematic side view of four flexure/nut-plate structures as shown in FIG. 39A, mounted in an E-block and electrically connected to a flex cable.

[0091] FIG. 39C is a schematic top view of another nut-plate/flexure embodiment with versatile, redundant connector conductor tabs.

[0092] FIG. 40A is a top view of a gimbaled flexure embodiment which is dimensioned to operate under a minimal load.

[0093] FIG. 40B is a top view of the conductor configuration employed in the flexure shown in FIG. 40A.

[0094] FIG. 40C is an enlarged partial top view of the flexure shown in FIG. 40A.

[0095] FIG. 40D is a schematic side view of a transducer/flexure with a pre-bend near its distal end.

[0096] FIGS. 41-45 are schematic top view layouts of sheet intermediate materials used in a production method of the present invention.

[0097] FIG. 46 is a top view of a flexure resulting from the process illustrated in FIGS. 41-45. Relative dimensions of the final flexure structure are shown.

[0098] FIGS. 47-49 are schematic top view layouts of sheet intermediate materials used in another production method of the present invention.

[0099] FIGS. 50A and 50B show working-side views of two modified forms of transducer chips.

DEFINITIONS

[0100] Terminology in the specification and claims should be interpreted in accordance with the following definitions.

[0101] A “flexure” is a flexible cantilever beam, with or without gimbal structure, for supporting a transducer adjacent a medium. A “suspension” may refer to a flexure, either alone or together with a flexure mounting system.

[0102] A “transducer” is an electromagnetic working organization, or unit, employed typically near the distal end of a flexure directly adjacent a medium in a read/write system. The transducer includes pole and coil substructures and the embedding material surrounding the substructures. A pole has a read/write working region. As used herein, the transducer does not include ancillary joined structure such as air bearing rails in a conventional flying slider. In at least one embodiment of the invention, the transducer is provided as an integrated component of the flexure. In other embodiments, the transducer is in the form of a chip which is joined to the distal end of the flexure. Each transducer has a working side which faces the recording surface in a magnetic medium during normal read/write operations.

[0103] At various locations throughout this specification reference is made selectively to the top and bottom sides of different structures. Where these terms are applied to a disk surface, it is assumed that the related disk is operating in a horizontal plane. Where these terms are applied to flexure, beam, transducer structures inside of the transducer, and top side refers to the opposite side.

[0104] The “Z-axis” is perpendicular to the surface of a recording medium and extends vertically through a trans-

ducer mounted on the free end of a flexure. A limited range of movement of the transducer along the Z-axis is allowed, as the transducer follows disk surface topography, during and between reading and writing activity. An “X-axis” and a “Y-axis” share a common origin with the Z-axis at the center of the distal edge of the transducer, and are perpendicular to each other in a plane which is co-planar with the upper-most surface of the medium when the transducer is operating in contact with this surface. The Y-axis is generally “longitudinal”, i.e., parallel to the length of the flexure. The X-axis is generally “lateral”, i.e., parallel to the width of the flexure. The X, Y and Z axes are illustrated in FIG. 1A relative to the distal tip of a transducer/flexure 60. The point of contact 62 between the transducer and disk 64 coincides with the origin of the coordinate system.

[0105] “Roll”, “pitch” and “yaw” refer to particular types of inclinational movement of a transducer relative to its static or idealized suspended position adjacent the surface of a medium. “Roll” refers to rotational movement about the Y-axis of a transducer adjacent the surface of a recording medium. “Pitch” refers to rotational movement around the X-axis of a transducer adjacent the surface of a recording medium. “Yaw” refers to rotation around the Z-axis of a transducer adjacent the surface of a recording medium.

[0106] “Load-bearing” is defined and used, inter alia, in the context of a cantilever flexure which has a mounting end and a free end extending generally horizontally over (adjacent) the surface (upper or lower) of a recording medium, for example, a rigid disk. The free end of the flexure supports and positions a transducer for reading and writing information on the surface of a medium. By deflection, the free end (distal end) of the flexure is applied by a force (load) against either the surface of the medium or an air-bearing directly on top of the surface. Elements of the flexure which provide significant support for the load, i.e., maintenance of desired Z-axis position of the transducer, are referred to as “load-bearing” structures. “Load-bearing” also relates to “articulation” (defined below) structure.

[0107] A “beam” is a transverse structural member which provides partial or complete support for a transducer adjacent the surface of a recording medium. The term “beam” may be used referring to the entire flexure body, or a load-bearing component of the body.

[0108] “Anisometric” means inequality of measurements or properties. The term is used in this application with reference to a beam’s axis-differentiated bending stiffness—i.e., regarding a beam having a preferential bending axis.

[0109] “Articulation” is used with respect to two structural members (sometimes referred to as “arms”) which are linked together, but allowed a certain degree of movement relative to each other. An “articulator” is a semi-rigid structure connecting first and second parts, which permits a selected range and type of mechanical movement of the parts relative to each other. An “articulating conductor” is an electrical conductor which also functions as an articulator. A “hinge articulator”, also referred to as a “beam/articulator structure”, is an articulator (unit, element) which bends around an axis perpendicular to a line centrally and directly connecting the two parts (also referred to as a “longitudinal axis”). A “torsional articulator” is an articulator (unit, element) which twists around an axis centrally and directly connecting the two parts (longitudinal axis). A “torsional beam” is a tor-

sional articulator. A “mixed-mode articulator” (unit, element) is a hybrid of a hinge articulator and a torsional articulator.

[0110] “Hinge” is a connector between two parts which allows a degree of movement, i.e., bending, of the parts relative to each other.

[0111] “Proximal” is used to refer to the end vicinity of a flexure which is structurally anchored or secured to a read/write system frame or servo-control actuator. The proximal end of the flexure is also referred to as the “mounting end”.

[0112] “Distal” is used to refer to the end vicinity of the flexure which carries the transducer and is also referred to as the “free end”.

[0113] “Angular constant” is defined, relative to a cantilever flexure, as the degree of angular change at the distal tip of the flexure for a given deflection.

[0114] A “pad” (also referred to as an island) projects from a side or face of a flexure or a transducer chip and contacts the surface of a disk when the transducer/flexure is operating to read or write information from the disk. With respect to flexures which employ gimbals, a triangular organization of three pads is sometimes used, and referred to as a “tri-pad” or “trident” structure.

DETAILED DESCRIPTION OF INVENTION

[0115] The invention, resting strongly on the merged-functionality concept set forth above, involves load-bearing and articulating structures for use in suspensions relating to micro-flexures which support transducers in electromagnetic read/write systems. These structures take the forms of load-bearing conductors and transducers, hinge-like mechanisms, torsional beams, and flexure mounting systems which allow production and implementation of flexures with low angular constants, minimum mounting tolerances, and/or the capability of tolerant compliance of the transducer with an inherently irregular recording medium surface. An important aspect of some of the transducer/flexures disclosed and claimed in the present invention is the use of electrical conductors and transducers which are geometrically designed and arranged to provide load-bearing support, as well as articulable movement, between linked portions of the flexure body.

[0116] FIGS. 1A and 1B illustrate a micro-flexure 60 (flexure/conductor/transducer structure), including an integrated transducer, or transducer unit, which was originally described and claimed in parent U.S. Pat. No. 5,041,932. The transducer, which is a tiny portion of the overall structure pictured in FIG. 1A, is located at the distal tip shown at 62. This transducer includes magnetic pole structure and coil and conductor structure all embedded in a small volume of surrounding joiner structure. It is in the disclosure of the '932 patent that the notion of merged-functionality makes its important debut in the read/write, disk drive transducer/flexure context. It is also in the '932 patent that one finds the introduction of a load-bearing transducer unit. Reference to the text and drawings of the patent will reveal a novel transducer unit having pole structure unified with (and within) a disk-contacting wear pad (or projection), and generally planarly distributed, coupled coil structure which

extends generally in a plane parallel with the plane of the wear pad's disk-contacting face.

[0117] As shown in FIGS. 1A and 1B, micro-transducer/flexure 60 includes integrated load-bearing conductors 61a and 61b embedded within flexure 60 along its entire length (continuum structure). An integrated transducer is embedded within flexure 60 at its distal tip 62 where it contacts disk 64 during operation of the read/write system. A number of important features of the present invention, which are more extensively developed in the embodiments illustrated and described below, are fully present in the micro-transducer/flexure structure illustrated in FIGS. 1A and 1B. First, as shown in FIG. 1B, integrated conductors/beams 61a and 61b are massive enough relative to the entire flexure body 60 to support a significant portion of the cantilever load. According to the teachings of the '932 patent, conductors 61a, 61b occupy in the range of about 13% to about 40% of the full thickness of the body of flexure 60. Therefore, conductors 61a and 61b play a dominant mechanical role, and are referred to as “load-bearing conductors”. Another important physical attribute of conductors/beams 61a and 61b is their generally rectangular or “blade-like” cross-sectional shape which provides preferential (anisometric) bending, allowing the tip to move in a direction along the Z-axis. The blade-like shapes of conductors 61a and 61b are also contributors to a relatively high lateral-frequency characteristic for flexure 60. Still another interesting geometric feature of conductors 61a and 61b is their symmetrical organization about plane W which bisects flexure 60 along its length. Between their opposite sets of ends, these conductors are also referred to as substructure spans.

[0118] A second important load-bearing structure embodied in the transducer/flexure of FIG. 1A, as briefly mentioned earlier, is the transducer itself (the embedded pole structure and coil and conductor structure mentioned earlier) located at the distal tip of flexure 60. Unlike flexures/transducers in the prior art, such as transducers joined to massive load-bearing, sliders, in which the transducer carries essentially none of the deflected beam load, the transducer integrated in the distal tip of flexure 60 directly contacts disk 64 and carries 100% of the cantilever load—i.e., directly through the embedded pole, coil, and conductor structure. The uses of load-bearing conductors and a load-bearing transducer in a transducer/flexure device, provide examples of a major theme of the present invention, namely, to design multi-functional (i.e., merged-functionality) components so that structures, such as conductors and transducers, which traditionally have had no mechanical function in prior art devices, become “mechanical activists” in the present invention, in addition to playing their traditional roles of conducting electrical signals and handling magnetic flux.

[0119] A related micro-flexure structure 70 with load-bearing conductors, or conductor elements, and a proximal hinge, or hinge region, is illustrated in FIG. 2. Micro-flexure 70 includes two, relatively flat, blade-like conductors (continuum structure) 72 and 74. Conductors 72 and 74, which form a common conductive layer, are insulated from each other by space 75. Conductors 72 and 74, collectively, have a tapered shape, and are widest at proximal (mounting) end 76 and narrowest at distal (free, disk-confronting, transducer-carrying) end 78. End 76 is also referred to herein as a base region. A proximal stiffener layer, or stiffener, 80

overlays the proximal ends 76 of conductors 72 and 74. Stiffener 80 has a hole 82 centrally located above a hole 84 defined by conductors 72 and 74. Holes 82 and 84 are used for alignment of the suspension to a mounting surface in a disk-drive system. A rectangular window 86 in stiffener 80 provides access to the top sides of conductors 72 and 74 for electrical bonding. Distal and proximal bonding regions of conductors 72 and 74 are preferably gold plated. A second stiffener 88 extends from a “hinge region” 89 near the proximal end of the flexure, to the distal end of the flexure. Hinge region 89, defined by the gap between stiffeners 80 and 88, is shown more completely in FIG. 3A, FIG. 4 and FIG. 6. The structural regions located longitudinally on opposite sides of the gap are also referred to herein as arms. Four windows 90 in stiffener 88 provide access to the conductors for heating them in the process of connecting a transducer chip 92 to the bottom side of conductors 72 and 74. Chip 92 contains, for example, a probe-type read/write transducer (not illustrated), the probe in which extends toward the disk’s recording surface through a single, projecting contact (wear) pad, or projection, 97 (see FIG. 3B).

[0120] A top view of flexure 70 is illustrated in FIG. 3A. Conductors 72 and 74 are seen in hinge region 89 where they are separated by a gap 75. In addition to being tapered from hinge region 89 to the distal end of flexure 70, lateral edges 94a and 94b in the flexure are slightly concave—a design feature which has been found to yield improved (higher) torsional frequency characteristics.

[0121] Hinge region 89 of flexure 70 has the following preferred specifications. Conductors 72 and 74 and stiffeners 80 and 88 are type-302 (or type-304) stainless steel. The thickness of the hinge material, i.e., conductors 72 and 74, is 0.5-mils. (1 mil.= $\frac{1}{1000}$ -of-an-inch). The length of the hinge is 24-mils. These dimensions were selected for the purpose of maintaining a spring constant of approximately 2.5-mgs.-per-mil. Stiffeners 80 and 88 are 1-mil. thick. Thus, most of the bending which occurs when the flexure is deflected, occurs in hinge region 89.

[0122] The hinge design just described provides a number of important benefits. First, a lower angular constant is achieved relative to a non-hinged design. Optimal angular constant for a simple cantilever, such as the one illustrated in FIGS. 2 and 3A, is achieved when all the bending occurs at the base (i.e., a perfect hinge). In the flexure shown in FIGS. 2 and 3A, most of the bending occurs in the base 7% of the beam. This results in an angular constant of approximately 0.19°-per-mil. of deflection. Second, the hinge provides damping capability. Since most of the flexure is rigid, constrained-layer (electrically insulating) damping material, as illustrated in FIGS. 5A, 5B and 5C (discussed in detail below), can be added to the stiffened region without affecting the spring constant. The damping material can be positioned between the conductor and stiffener layers, and/or another set of damping and constraining layers can be added above or below the flexure if necessary to attenuate vibrational amplitudes. Third, the hinge provides improved drive tolerances. If a pre-bend is added to the hinge area of the flexure, the suspension can operate essentially flat—thus requiring less mounting space. This allows very close disk-to-disk spacing. Structures, considerations and benefits relating to the concepts of pre-bent flexures and disk-to-disk spacing will be more fully developed below.

[0123] The trapezoidal/concave edge shape of the flexure, overall beam thickness, and 350-mil. free beam length provide the following advantages. First, the shape provides good lateral stiffness. Lateral stiffness increases as the cube of width. High lateral stiffness is desirable for minimizing lateral vibrational movement. Second, by tapering the width at the tip, high lateral frequencies are achieved which are desirable for servo stability. Third, the “bugle” or concave-edge shape was found to have the highest torsional frequency of trapezoidal-like shapes. High torsional frequency is desirable for servo stability because there can be a significant off-track motion associated with the torsional mode. Fourth, the design has been found to avoid undesirable modal interactions. We have discovered that certain normal modes of vibration interact with others, causing high vibrational amplitudes. Such interaction is caused by frictional changes at the transducer/disk interface with contact pad angle changes. Accordingly, the following situations should be avoided: (1) lateral frequency 1 \times , 2 \times or 3 \times the torsional frequency, and (2) torsional or lateral frequency of 1 \times or 2 \times any first or second bending frequency.

[0124] FIG. 3B is a side view of the distal end of flexure 70, illustrating the mounting of transducer chip 92 on flexure 70. Stiffener 88 is separated from conductor 72 by an adhesive (bonding) layer 95. Solder structures, plus adhesive and/or conductive epoxy structures in some cases, such as the solder structures shown at 96a and 96b, electrically and mechanically connect conductor 72 to chip 92. Full mechanical load is transmitted through these connections. Single pad 97 is preferably made of amorphous diamond-like carbon (DLC), and is positioned on the bottom side (in FIG. 3B) of chip 92, near the center of its trailing edge, as shown in FIG. 3C. When transducer/flexure 70 is in its operating mode, pad 97 contacts the uppermost surface of disk (medium) 98. The single-pad configuration which is employed in transducer/flexure 70 and illustrated in FIGS. 3B and 3C is characteristic of the flexures shown in FIGS. 1-9, which do not include gimbals. When a single pad is employed in a non-gimbaled flexure, facets are polished around the pad to provide full transducer signal through a range of static mounting tolerance. Other pad configurations and considerations are discussed below. Similar to the integrated transducer/flexure structure shown in FIGS. 1A and 1B, transducer chip 92, as shown in FIG. 3B, bears the entire cantilever load of the deflected beam. Thus, the need for a separate load-bearing structure is avoided.

[0125] In the configuration shown in FIG. 3B, chip 92 contains transducer pole structure and coupled coil structure organized and distributed in the following fashion. The read/write working portion of the pole structure extends within pad 97 to the bottom (in FIG. 3) disk-contacting face of the pad. The coupled coil structure occupies the generally horizontal (in FIG. 3) plane of the main body of the chip.

[0126] Shifting focus briefly onto the modification shown in FIG. 3D, here chip 92 contains pole structure and coil structure organized and distributed in a somewhat different manner. Specifically, here, both of these structures occupy a plane which extends generally normal to the long axis of flexure 70. This planar region is indicated generally at 99. Here too the read/write working portion of the pole structure extends within pad 97 to the bottom face of the pad. This organization is referred to as a “pin head” type arrangement.

[0127] The FIG. 3D embodiment suggests the possibility of creating yet another kind of transducer chip which is fully planar, and intended for suitable mounting at the end of a beam/flexure, in a disposition with its plane, including the plane of the body of the chip, normal to the long axis of the beam/flexure. Such a situation is specifically illustrated and described in a portion of this specification set forth below. In all cases the transducer is load-bearing.

[0128] The performance or flexibility of the hinge region can be modified or tuned by, for example, altering the dimensions of the conductors in the hinge region, or by changing the width of the gap between stiffeners, as illustrated in FIG. 4. Here, for example, an illustrated hinge 100 includes conductor portions 102 and 104 flanked by stiffeners 105 and 106. Flexibility of conductor portions 102 and 104 in the hinge region can be altered or tuned by changing the gap width. For example, if the hinge gap edge is relocated to line 109, then hinge flexibility is increased. Similarly, other changes in conductor geometry or material composition provide different ways of tuning the hinge.

[0129] FIG. 5A shows a cross section of flexure 70 as illustrated in FIG. 3A. Conductors 72 and 74 are separated by air gap 75, and are bound to stiffener 88 via adhesive layer 95 (a resin). Stiffener 88 and layer 95 collaboratively form joinder structure for the conductors. Importantly, resin 95 functions to insulate conductors 72 and 74 electrically from stiffener 88. Stiffening and/or vibrational damping can be enhanced by selecting an appropriate type, amount and application of the adhesive resin. Adhesive layer 95 is preferably 1.0-mil. thick. Adhesive resins which have been used to bond conductor and stiffening layers in laminant flexures of the present invention include epoxies, acrylics and polyimides in both liquid and sheet forms. For example a liquid epoxy resin available from Bondline, referred to as 6555™, can be used in the present invention. An epoxy resin in sheet form is available from AI Technology, referred to as TK7755™. An acrylic resin which can be used in the present invention is sold by DuPont under the trademark Piralux™. A polyimide resin sold by DuPont under the name Kapton™ is another suitable alternative. Other good adhesive layer materials have been identified by Hutchinson Technology Incorporated which is located in Hutchinson, Minn.

[0130] FIGS. 5B and 5C illustrate another feature of the invention which may be employed to provide vibrational damping in addition to any damping effect which may be achieved by resin layer 95 which is sandwiched between conducting and stiffening layers. In FIG. 5B, a damping layer 112 is continuously sandwiched between stiffener 88 and a constraining layer 114, which, for example, may be stainless steel. Although it is possible to use a damping layer without a constraining layer, better results are obtained when the damping material is sandwiched between more rigid solids. This is because the damping effect relies on the absorption of shear energy in the damping layer. The amount of shear energy produced from vibrational motion of the flexure, and subsequently absorbed by the damping layer, is increased by using a constraining layer. FIG. 5C is the same as FIG. 5B except that it shows that damping layer 116 may be applied on the bottom side of the flexure, where it is sandwiched between conductors 72 and 74, and constraining layer 118. As shown in FIG. 5C, damping layer 116 spans gap 75 between conductors 72 and 74. However, it is also possible for damping layer 116 to be omitted in the region

of gap 75, analogous to adhesive layer 95. Conversely, it is possible for adhesive layer 95 continuously to span gap 75 between conductors 72 and 74. A material known as ISD110™ or ISD112™, available from 3M Corporation, is suitable for damping layers 112 and 116.

[0131] FIG. 6 shows a side view of hinge region 89 of flexure 70. Proximal stiffener 80 and distal stiffener 88 flank hinge region 89. Resin layer 95 extends continuously in the region where stiffeners 80 and 88 overlay conductors 72 and 74. Further considering some of the features which characterize hinge or hinge region 89, within the elongate body of flexure 70, the hinge region can be thought of as having longitudinal boundaries which are indicated in FIG. 6 by dash-dot lines 89a, 89b. The conductor material which makes up hinge region 89 is homogeneous (outside of these two longitudinal boundaries) only with material which lies bounded between common (shared) spaced facial planes which intersect the regions of boundaries 89a, 89b. These two common facial planes are illustrated by dash-dot lines 73a, 73b in FIG. 6. Another way of viewing this is that the material in hinge region 89 is homogeneous, beyond boundaries 89a, 89b, only with extensions of the conductor material itself which makes up the hinge region.

[0132] FIG. 7 schematically illustrates change in adhesive conformation due to flexure deflection. By selecting an appropriate type of resin, and by controlling the amount used, it is possible to vary the degree of stiffening obtained in the stiffened region. The type and amount of resin 95 can also be selected to provide an advantageous vibrational damping effect. Resins typically exhibit varying degrees of elasticity. In FIG. 7, rectangular resin section 132 is stretched into trapezoidal resin section 134 when the flexure is bent. A greater degree of stiffening is therefore achieved by selecting a resin which is relatively unyielding or resistant to stretching.

[0133] FIGS. 8 and 9 illustrate views of a modified flexure, which in many respects is the same as the flexure shown in FIGS. 2 and 3A. An important difference, however, is that in the flexure shown in FIGS. 8 and 9, four conductors are provided in the conductive layer. It is sometimes necessary to provide more than two conductors to the distal end of the flexure. For example, in transducer/flexure structures which include a magnetoresistive read substructure, at least four conductors are required. FIGS. 8 and 9 illustrate that the concept of the present invention, characterized by multiple load-bearing conductors, may encompass designs which include many more than two conductors, even though most of the flexures specifically described in this application include only two load-bearing conductors.

[0134] In FIG. 8, a flexure 140 includes a stiffener 142 and a stiffener 144 overlaying load-bearing conductors 146, 148, 150 and 152. As in the previously described design, although not shown in FIG. 8, the stiffeners are bound to the conductors by an insulative adhesive resin. Transducer chip 154 is directly bonded to the bottom side of conductors 146, 148, 150 and 152, substantially as shown in FIG. 3B. A single wear pad is provided on the bottom side of chip 154 near the center of its trailing edge. FIG. 9 shows the outline of the conductors in dashed lines. Note that in this structure, the conductors are distributed symmetrically with respect to an imaginary plane which bisects the flexure along its length.

[0135] Turning attention now away from non-gimbale structures made in accordance with the teachings of this invention toward gimbale structures, it is important to note that gimbale-type structures are fundamentally different from the flexure/transducer structures which have been described so far above. They are different in that gimbal mechanism allows the transducer chip ranges of pitch and roll motion independent from the supporting flexure body. Gimbaling movement of a transducer chip has been recognized as an extremely important mechanical feature with respect both to flying structures and to contact-capable structures. In the non-gimbale flexures described above, the conductors have been characterized as “load-bearing” structures because of the relative size and configuration in a proximal hinge region and throughout the body or length of the flexure. In the descriptions which now immediately follow, gimbal flexures are described in which the conductors fulfill additional mechanical load-bearing and articulating functions, such as hinge and torsional flexibility for a distally-located gimbal which permits pitch and roll movement of the transducer chip relative to the flexure body. These gimbale configurations are illustrated collectively in FIGS. 13-30, inclusive, and in each of the designs therein illustrated, the conductors contribute functionally in at least three important ways: (1) to conduct electrical signals between a transducer and external circuitry; (2) to bear all or a portion of the deflected cantilever load, at least at some point along the length of the flexure; and (3) to provide a gimbal platform (a transducer-carrying platform) for mounting a transducer chip. Accordingly, the embodiments that are shown in the collection of figures just mentioned are referred to as “conductor gimbaling flexures”.

[0136] A further matter to note is that in all of the flexure/transducer structures which are described and discussed in this specification, there exists, fundamentally, a three-layer flexure structure to which there is attached or joined, in various ways, a transducer chip. The three layers in each flexure structure include a conductor layer, an adhesive layer, and a stiffener layer, and in each of these layers, and in the different embodiments, the specific configurations of the components in the layer are somewhat different. Relying on the fact that all now-to-be-described flexure/transducer assemblies have, in many respects, similar organizational characteristics, descriptions of these embodiments will be presented in a more conversational flow of structural and functional qualities, rather than with a mechanistic listing of parts followed by a functional description, and with an effort to focus principally, and inter alia, on key differences that differentiate the different embodiments.

[0137] Thus, and turning attention first of all now to FIGS. 10, 11, 12A, 12B and 12C, here there is illustrated an embodiment of the invention which employs what is referred to as a “load-button” gimbal. This embodiment closely resembles a head/flexure design previously disclosed and claimed in co-pending U.S. application Ser. No. 07/783, 619. Here a transducer/flexure 160 is principally supported by load-bearing conductors 162 and 164. At the distal end of conductors 162 and 164 are articulator “ribbons” 166a and 166b on which a transducer chip 168 is mounted. A load button 170 is provided on the top side of chip 168 around which rocking, inclinational movement of the chip is allowed. It is important to note, however, that the load button could also be provided on the bottom side of stiffener 180 for

example, by creating a downwardly protruding dimple. The height of load button 170 is approximately equal to the thickness (0.5-mils) of conductors 162 and 164 plus the thickness of adhesive layers 174 and 176. Adhesive layers 174 and 176 facilitate lamination of stiffeners 178 and 180 on top of conductors 162 and 164. FIG. 11 shows assembled flexure 160 with detached transducer chip 168. FIG. 12A shows the top view of assembled flexure 160.

[0138] FIG. 12B illustrates the mounting configuration of transducer 168 on flexure 160. In the region of flexure 160 where transducer 168 is attached, stiffener 180 is separated from conductor ribbon 166b by air. As shown in FIG. 10, adhesive layer 176 only extends distally to the point where ribbons 166a and 166b begin. Transducer 168 is bonded by solder structure 188a and 188b to conductor ribbon 166b. The bottom side of transducer 168 has three wear pads 190a, 190b and 190c (see particularly FIG. 12C) which contact the disk surface in a triangular (tripodic) pattern when the transducer is operating. Ideally, sufficient load is applied to flexure to maintain contact between each of the pads and the disk surface at all times.

[0139] In FIG. 13, flexure 200 includes conductors 202 and 204 which are spaced apart from each other and extend along the entire length of flexure 200. A gimbal structure or region 206 of the conductors is located near the distal ends of the conductors. Each conductor contributes one of a pair of parallel platforms (or articulated portions) 208a and 208b which are located centrally within a cut-out gimbal region and serve collectively as a mounting platform for transducer chip 210. This mounting platform is located adjacent what is also referred to herein as the transducer unit receiving end of flexure 200. Platforms 208a, 208b are also referred to as paddle portions. Stiffeners 212 and 214 are laminated, via adhesive as previously described, onto the tops of conductors 202 and 204 on opposite sides of gap 213 which defines a hinge region. The stiffeners rigidify portions of conductors 202 and 204 outside of hinge region 213. Additionally, the stiffeners’ continuity from side-to-side provides structural compliance between the two load-bearing conductors 202 and 204. In gimbal region 218 toward the distal end of stiffener 214, two additional stiffeners 220 and 222 are laminated above the gimbal region 206 of conductors 202 and 204. Stiffeners 220 and 222 serve to coordinate corresponding conductor regions and to isolate mechanical articulating conductors, i.e., conductive torsional beams, which will be shown and discussed in more detail below.

[0140] FIG. 14 shows a magnified top view of gimbal region 206 of conductors 202 and 204. Conductors 202 and 204 are distinctively shaded to assist the viewer in understanding the mechanical relationship and electrical isolation of the conductors. Platforms 208a and 208b are coordinated and jointly stiffened on the top side by stiffener 222. On the bottom side of platforms 208a and 208b, transducer chip 210 is attached. It is apparent that platforms 208a and 208b also function as electrically distinct leads to transducer 210. Torsional beams (articulators, units, elements) 230a and 230b allow platforms 208a and 208b a limited range of pitch flexibility. Similarly, torsional beams (articulators, units, elements) 232a and 232b allow platforms 208a and 208b a limited range of roll flexibility. Beams 230a, 230b, 232a, 232b, collectively, constitute articulator structure which is referred to herein as being characterized by mechanical and electrical homogeneity—i.e., merged functionality. The

gimbaling motion permitted by the torsional beams makes possible accommodation of angular or topographic irregularities on the surface of a rigid medium. Although the surface of a medium is ideally flat, in reality, irregularities due to, for example, micro-roughness, polishing/texturing scratches, disk waviness and/or "cupping", non-parallelism of the spindle and actuator axes, and non-squareness of either of these axes and the disk surface, are inherently present to some degree. The torsional beams also permit the head/flexure to accommodate static mounting tolerances.

[0141] FIG. 15A shows a top view of the flexure shown in FIG. 13, after assembly. In FIG. 15A portions of conductors 202 and 204 can be seen in hinge region 244 and through window 242 which allows electrical bonding through the top side of flexure 200. Stiffener 212 also has hole 240 concentrically located above conductor hole 241. Holes 240 and 241 are used for positioning the suspension on a mounting surface. Near the distal end of flexure 200, gaps between stiffeners 220 and 222 define flexible torsional beam portions of conductors 202 and 204.

[0142] An important feature of all the gimbaled flexures described in this application is the configuration of pads (the three contact pads) located on the bottom side of the transducer chip for contacting the surface of the recording medium during read/write operation. Unlike the non-gimbaled flexures, a fundamental objective in the gimbaled designs is to maintain a parallel relationship (zero-angle-of-attack) between the plane of the transducer chip and the surface of the recording medium. For this purpose, a load force is applied, via the deflected flexure, urging the transducer chip into load-bearing contact with the disk's surface. Multiple pad contact points on the bottom of the transducer chip define a plane of interfacial contact between the chip and the disk. Ideally, torsional beams and/or hinges, load buttons, etc. permit the interfacial contact plane between the disk and the pads to remain intact, despite mounting tolerances and disk surface aberrations, throughout normal read/write system operation. The most common pad configuration employed in the gimbaled flexures of the present invention, consists of a triangular arrangement of three pads, one located in the center of the trailing (or distal) edge of the transducer chip, and the other two pads being located at opposite front corners of the chip. The pole, which is contained typically in the trailing pad, is preferably in constant contact with the surface of the media for the most high-level read/write performance. While this is a typical arrangement, a reverse kind of arrangement is possible, and may offer certain performance advantages in selected applications. More particularly, the central, pole-containing pad could be located adjacent the leading edge of the chip. With this type of arrangement, relative motion between the chip and disk tends to drive the leading-edge pole-containing pad into even more intimate working confrontation to the recording surface in a medium. Further, it is possible that pole structures might be provided in two, or in all three, of the pads.

[0143] Maximum stability is achieved when the pads are located as far apart as possible, consistent with chip size and disk flatness constraints. During pad-disk contact, the pads may be perturbed in the Z direction by hitting pits or asperities in the surface. When this occurs, the downward load must be great enough to restore contact quickly between the pads and the disk. Pad size and shape is not

critical except that it is desirable to have the pad that contains the pole be as small as possible to minimize spacing loss, inasmuch as the actual contact point on the pad varies due to disk waviness. For wear reasons, it may be desirable to have larger pads which can sustain larger removed wear volumes. Pads that become too large may create an air-bearing surface that causes a contact-intended transducer to fly rather than to slide. In addition, larger pads may exhibit higher adhesion forces, and consequently additional friction and stiction during operation. Round pads may be desirable so that debris will not collect on a flat leading edge, as has been observed in some cases on square or rectangular pads.

[0144] FIGS. 15B and 15C illustrate the pad configuration used on the bottom side of transducer chip 210. Stiffener 214 is laminated, via adhesive 247, to conductor 202. Conductor 202 is electrically and mechanically attached to the top side of transducer chip 210 by load-bearing solder structures 248a and 248b. The chip may also be attached to the conductors by processes employing brazing or conductive epoxy materials. As shown in FIG. 15C, pads 250a, 250b and 250c are arranged in a maximally separated triangular configuration on the bottom side of transducer chip 210.

[0145] A large number of possible pad configurations may be employed in the gimbal structures of the present invention. It is generally preferred to use not more than three pads because four or more contact points create the possibility for rocking of the chip on the disk surface. It is possible for all three pads to be directly connected to the transducer chip, or alternatively, as described in detail below, one or more of the pads may be located on other parts of the flexure which articulate relative to the transducer-carrying portion of the flexure. In most of the gimbal structures described in this application, the pole-containing pad is located on the trailing edge of the chip body. However, as shown by the arrow in FIG. 15C, and as was mentioned earlier, it is possible, and sometimes preferable, to position the pole-containing pad on the leading edge of the chip (by rotating the chip 180°, or by reversing the direction of disk rotation). We have discovered that the pad(s) which is positioned on the leading edge of the chip experiences a significant amount of friction with the disk surface, causing an unloading affect on the pad or pads located on the trailing edge of the chip. This phenomenon must be taken into account when deciding where to position pitch articulators in a gimbal. Further, we have found that electromagnetic signal performance can vary significantly depending on whether the pole-containing pad is on the leading edge or on the trailing edge of the chip body. In general, we have observed a significant increase in signal magnitude when the pole is positioned on the leading edge (instead of on the trailing edge) of the chip.

[0146] In a tri-pad arrangement of the type shown in FIG. 15C, where the transducer chip is mounted on a gimbal permitting all three pads to contact the surface of the medium continuously during normal operation, the transducer chip remains in a substantially parallel orientation, i.e., at a zero-angle-of-attack, relative to the surface of a disk. This feature of the disclosed gimbal structures, represents a major departure from prior transducers/flexures which exhibit substantial angles-of-attack relative to a disk's surface. Positioning the transducer chip to operate at a zero-angle-of-attack relative to the disk surface provides the capability of employing a transducer design which, due to a

particular coil structure, requires the main pole structure to be located inward from the transducer chip's trailing edge.

[0147] For example, as illustrated in **FIGS. 15D and 15E**, it is sometimes desirable to locate a pad containing the main pole, inward from the trailing edge of the chip. Flexure/transducer **251** is supported by beam **252**. Transducer chip, or chip body, **253**, which is generally quite thin and planar, is mounted on the bottom side of beam **252**. Projecting tri-pads **254a**, **254b** and **254c** are located on the bottom side of body **253**, defining a plane of interfacial contact between the transducer and the disk's surface **256**. Inductively coupled to the pole structure is a generally planarly distributed coil, or coil structure, which lies in the plane of chip body **253** in a coil region **255** generally designated by dashed lines in body **253**. As shown, it is sometimes desirable to employ a coil design which extends forward and backward from pole **254a** along the Y axis. In such a design, it is necessary to position the pole-containing pad inward from the trailing edge of the chip. This design goal is problematic, i.e., sometimes impossible, in a flexure/transducer which positions the chip with a significant angle-of-attack relative to a disk's surface. This is because, as the pole is moved inward from the trailing edge of a chip body, which is oriented with a significant angle-of-attack, it becomes impossible for the pole to contact the disk. The distance between the pole and the disk becomes greater and greater as the distance between the pole and the trailing edge increases. Accordingly, the flexibility for implementing alternative pole and coil designs in transducers which operate at a significant angle-of-attack is quite limited. It is important to note that the positioning of pitch and roll articulators in a given gimbal configuration is primarily determined by the locations of the contact pads. For example, as the pole-containing pad is moved inward from the trailing edge of the chip body, pitch articulators in the gimbal must also be moved in the same direction in order to maintain the desired gimbal performance and load allocation among the pads.

[0148] In contrast, by providing a flexure/gimbal structure, which is capable of supporting a transducer chip in parallel orientation (zero-angle-of-attack) relative to a disk's surface, a great improvement in transducer design flexibility is made possible. In the flexure/gimbal structures of the present invention, the pole-containing pad may be located practically anywhere on the working side or surface of the chip without altering the operable spacing (or contact relationship) between the pole and the disk surface. The entire planar body of the transducer chip is available for containing coupled pole structure and coil structure.

[0149] **FIG. 16** is a thin-layer section including the pitch-accommodating torsional beams of the flexure shown in **FIG. 15**. The structures of torsional beams **230a** and **230b** are analogous to conductor hinge **89** in **FIG. 6**.

[0150] **FIGS. 17A and 17B** illustrate a portion of a conductor gimbaling flexure which in all respects is the same as the flexure shown in **FIGS. 13-16**, except that an additional damping layer is added. In **FIG. 17A**, damping layer **260** covers substantially the entire gimbal. Damping layer **260** may be, for example, an elastomer available from 3M under the trademark ISD110™ or ISD112™. The material is preferably diluted with ethylacetate to 10% (V/V) of its original concentration, and then applied to the top of the

flexure in the gimbal region as shown in **FIG. 17A**. Use of such a membrane layer results in significant vibrational damping. It is believed that shear energy is absorbed by the membrane, particularly in regions of the gimbal where the maximum amount of vibrational movement is expected to occur. A thin membrane can be employed for this purpose without significantly stiffening the pitch and roll motions otherwise permitted by the gimbal. However, to minimize further any stiffening effect of the membrane on the gimbal, and as is shown in **FIG. 17B**, a modified damping membrane configuration includes four discrete membranes, or membrane patches, **262a**, **262b**, **264a** and **264b**, each of which bridges two separate conductor portions in an area where the greatest degree of relative movement between the portions is expected to occur. It is preferable to select a damping material which exhibits a relatively high degree of elasticity under static conditions, and a high degree of stiffness when subjected to a high-frequency condition.

[0151] Another desirable way of employing a damping membrane, such as the ones illustrated in **FIGS. 17A and 17B**, is to position the damping membrane between either stiffener and conductor, or the flexure and an additional constraining layer. Ideally, the adhesive layer, which is already required in each of the laminant flexures described herein, and which can furnish damping action, may extend continuously through the gimbal region. The adhesive layer may extend through all of the gaps between stiffeners **214**, **220** and **222** in the gimbal region. Alternatively, and in order to minimize any stiffening effect of the membrane on the gimbal, the adhesive layer may bridge gaps between stiffeners only in discrete regions where maximum movement between the stiffeners is expected to occur, similar to the configuration shown in **FIG. 17B**.

[0152] **FIG. 18** shows another embodiment of a gimbaled transducer/flexure which employs a membrane interconnecting a flexure body and a transducer chip. In the structure shown in **FIG. 18**, the membrane functions primarily as a gimbaling structure and possibly also a damping layer. Transducer/flexure **270** includes a flexure frame portion **271** from which trace conductors **272a** and **272b** extend to transducer chip **273**. Three contact pads **274a**, **274b** and **274c** (dashed lines) are located on the bottom (working) side of transducer chip **273**. The transducer pole (not shown) is preferably located in contact pad **274a**. In this design, trace conductors **272a** and **272b** are downsized (compared to previously described conductors) and shaped (folded or curved) so as to make the conductors insignificant structural contributors in the transducer/gimbal region. Elastomeric membrane **276** spans the gap region between flexure frame portion **271** and transducer chip **273**. As already described with reference to **FIGS. 17A and 17B**, a membrane interconnecting a flexure frame and a transducer chip can be employed advantageously for the purpose of damping vibrations. However, the primary function performed by membrane **276** is to bear the cantilever load while permitting ranges of pitch and roll movement of transducer chip **273**. Membrane layer **276** is the only significant load-bearing connection between frame portion **271** and transducer chip **273**. By selecting the appropriate type, thickness and configuration, membrane **276** may function as a gimbal structure to allow pitch and roll movement of transducer chip **273** independent from flexure frame portion **271**, while possibly

also damping vibrations. Membrane 276 is preferably sandwiched between flexure frame subportions and/or conductors.

[0153] FIGS. 19A, 19B and 20 illustrate a flexure which is similar to the one illustrated in FIGS. 13-16 except for several important differences. As shown in FIG. 19A, flexure 280 has two hinges 281 and 282. Hinge 281 is characterized by a cut-out window in stiffener 283 near its proximal end exposing relatively thin conductors 284 and 286. The outlines of conductors 284 and 286 underneath the stiffeners are shown in dashed lines. It is apparent that, although the reduced dimensions of conductors 284 and 286 in the proximal hinge region (relative to the dimensions of previously described conductors) diminishes the load-bearing function of the conductors in that region, in the intermediate region of the flexure the conductors are wider, and therefore carry a significant portion of the load. The configuration of modified hinge 280 results in a higher spring constant for accommodating higher loads in comparison to the loads carried by previously described flexures.

[0154] The configuration of hinge 282 near the distal end of the flexure is similar to previously described hinges in that conductors 284 and 286 are the sole load-bearing structures in that region. Gimbal 288 allows pitch and roll movement of stiffened transducer-carrying platform 289. Similar to the gimbal shown in FIGS. 13-15, gimbal 288 employs torsional beams 290a and 290b to allow roll movement of platform 289 independent from the body of flexure 280. Pitch movement is facilitated by hinges (articulators, units, elements) 292a and 292b which are rearwardly displaced from the center of the platform in order to equalize load distribution among the three medium-contacting pads (not shown). The use of hinges instead of torsional beams provides the important advantage of increased longitudinal and yaw stiffness. Another advantage of using hinges to provide pitch movement instead of torsional beams is that overall width of the flexure in the gimbal region can be reduced. The pitch-permissive hinges also provide a platform for dispensing adhesive. The configuration of conductors 284 and 286 in gimbal region 288 of flexure 280 is shown in FIG. 19B. Conductor 286 enters the gimbal mechanism through roll-permissive torsional beam 290a, and enters the transducer-carrying region through pitch-permissive conductor/hinge 292a to end in transducer-carrying semi-platform 293a. Similarly, conductor 284 enters the gimbal mechanism through roll-permissive torsional beam 290b, and enters the transducer-carrying region through pitch-permissive conductor hinge 292b to end in transducer-carrying semi-platform 293b.

[0155] FIG. 20 shows a side view of flexure 280 operating on disk 295. Most of the bending which results from deflection of the flexure occurs in hinges 281 and 282. Gimbal 288 mounts and supports transducer chip 296. A "tri-pad" configuration (only two pads 297a and 297b are shown), as previously described, exists for maintaining an interfacial contact plane between chip 296 and the surface of disk 295.

[0156] Flexure 300, as shown in FIG. 21, is the same as flexure 280 shown in FIG. 19, except that the dimensions of conductors 302 and 304 in region I are modified, and that flexure 300 is pre-bent in proximal hinge region 306 (FIG. 22A). This prebend exists along an axis 306a (see FIG. 21) which defines a preferential bending axis for flexure 360.

[0157] Stiffener layers 301a, 301b, 301c and 301d are laminated on top of conductors 302 and 304. The lateral dimensions of conductors 302 and 304 in region I are shown in dashed lines because the conductors are covered by stiffener 301a. The reduction of conductor width in region I can result in a significant reduction in capacitance levels.

[0158] The conductors can be made of different materials. However, a number of factors must be considered when selecting an appropriate conductor material. In addition to being able to conduct electricity, the conductor material must exhibit appropriate physical/mechanical properties within the geometric and dimensional limitations which dictate the operation and overall size of the flexure. When the conductors function as the only load-bearing components of the proximal hinge, as in previously described designs, it is preferable to use materials, such as stainless steel, which have a relatively high elastic (Young's) modulus resulting in higher modal frequencies, and high tensile strength which can therefore support higher loads. However, in flexures such as the ones shown in FIGS. 19-22B, where the conductors are relatively insignificant load-bearing components in the proximal hinge, beryllium copper is a suitable choice of material. With some conductor materials, such as stainless steel, it is preferable to gold-plate the entire surface for at least two reasons. First, gold-plating in the bonding regions facilitates a solder connection. Second, gold-plating the entire stainless steel beam reduces resistance. When beryllium copper is used as the conductor material, it is only necessary to gold-plate the bonding regions.

[0159] FIG. 22A shows flexure 300 in its unloaded position U (solid lines) and in its loaded position L (dash-dot lines) relative to disk 310. By pre-bending flexure 300 in hinge region 306 (on axis 306a), flexure mount 312 can be parallel to the disk surface, thereby, minimizing disk-to-disk spacing.

[0160] FIG. 22B illustrates a modification of flexure 300 which involves the use of gimbal-motion-limiting guides, or "bumpers", for the purpose of avoiding extreme, potentially catastrophic movement of gimbal parts out of the plane of flexure 300 in the case of a relatively high-shock situation. Read/write systems are sometimes subjected to high-shock forces, for example, when a system is dropped or moved abruptly. In this situation, gimbal parts which are connected by relatively small hinges or torsional beams, may be moved, bent or broken permanently away from their operable positions. Accordingly, the modification of flexure 300 shown in FIG. 22B, provides motion-limiting bumpers for preventing extreme movement of the gimbal parts with respect to the flexure body and to each other. In FIG. 22B, flexure 300 includes conductors 302 and 304, the configuration of which has already been discussed referring to FIGS. 19A through 22A. Stiffeners 312a, 312b, 312c and 312d are laminated on top of conductors 302 and 304. Stiffeners 312b, 312c and 312d differ from previously described stiffeners in that they include tabs which extend over air gaps between gimbal parts. These tabs partially cover (but do not touch) exposed conductor regions in an adjacent gimbal part. For example, tabs 314a, 314b, 314c and 314d extend over conductor edge regions of gimbal part 317. Bumpers 314a, 314b, 314c and 314d significantly limit the extent to which gimbal part 317 can move above the plane of flexure 300 in a high-shock situation, while still allowing the desired range of roll torsional movement of the

transducer chip independent from the body of flexure **300**. Similarly, tabs **316a** and **316b** are extensions of stiffener **312c**, protruding over conductor edge regions of transducer-carrying platform **318**. Bumpers, or tabs, **316a** and **316b** prevent extreme movement of platform **318** above the plane of gimbal part **317** or the body of flexure **300**, while still allowing the desired degree of pitch movement of platform **318** independent from the rest of flexure **300**. Extreme movement of the gimbal parts below the body of flexure **300**, can also be prevented by outwardly extending tabs **319a**, **319b**, **319c** and **319d**. Each of tabs **319a**, **319b**, **319c** and **319d** extend over a gap separating gimbal part **317** from the body of flexure **300**, and over an exposed conductor region defined by corresponding cut-outs in stiffener **312b**. It is apparent (although not shown) that similar outwardly extending tabs could be employed to limit extreme movement of platform **318** below the plane of gimbal part **317**.

[0161] FIGS. 23-25 illustrate modified conductor gimbal configurations employing conducting articulators, namely, torsional beams, to allow limited ranges of pitch and roll movement of a transducer platform independent from a flexure body. Each of the gimbaling conductor structures shown in FIGS. 23-25 can be implemented, with corresponding stiffeners, in flexures such as the ones shown in FIGS. 13-22B. Specifically, the gimbaling conductor structure shown in FIG. 14 could be replaced (along with appropriately modified stiffeners) with any one of the structures shown in FIGS. 23-25.

[0162] In FIG. 23, gimbaling conductor configuration **320** is similar to the one shown in FIG. 14, except that pitch-permissive torsional beams **322a** and **322b** are located laterally and externally from roll-permissive torsional beams **324a** and **324b**. In contrast to the FIG. 14 configuration, where pitch-permissive torsional beams **230a** and **230b** connect directly to transducer-carrying platforms **208a** and **208b**, in the FIG. 23 configuration, roll-permissive torsional beams **324a** and **324b** connect directly to transducer-carrying platforms **325a** and **325b**.

[0163] FIG. 24 illustrates the point that gimbaling conductor configurations may employ torsional beams which are obliquely angled relative to lengthwise axis AX of the flexure. In gimbaling conductor configuration **330**, the axes of external torsional beams **332a** and **332b**, and internal torsional beams **334a** and **334b** are each obliquely angled relative to axis AX. The FIG. 24 configuration also illustrates the point that the torsional axes of torsional beam pairs, i.e., **332a** and **332b** versus **334a** and **334b**, do not need to be perpendicular to each other. These beams perform as mixed-mode articulators, with both hinging and torsional action.

[0164] In FIG. 25, the gimbaling conductor configuration is similar to the FIG. 14 configuration, except for the addition of longitudinal stiffening arms **342a** and **342b**, each of which may be described as a simply supported cantilever with applied moment. Ideally, arms **342a** and **342b** should connect with **344a** and **344b**, respectively, as close to the center of the gimbal as possible.

[0165] All of the gimbaling conductor configurations mentioned so far, embody a single pair of conductors. In contrast, FIG. 26 illustrates a gimbaling conductor configuration with four conductors **352**, **354**, **356** and **358**. These four conductors are differently shaded in order to illustrate

and clarify their respective paths from the flexure body into and through the gimbal. Each of conductors **352**, **354**, **356** and **358** contributes two torsional beams and one quadrant of a transducer-carrying platform. For example, conductor **352** runs through torsional beam **352a**, then through torsional beam **352b** and ends in transducer-carrying platform quadrant **352c**. Each of the other conductors follows a similar complementary path.

[0166] FIG. 26 also illustrates that the four right-angle torsional beams shown in the FIG. 14 configuration can be replaced with four pairs of beams, wherein each pair includes two oblique beams. Each pair of oblique beams, for example, the pair including beams **360** and **352a**, is referred to as a “triangular, dual-beam torsional articulator”. The triangular dual-beam torsional articulator provides greater stiffness in comparison to the single right-angle beam systems previously described. It is also possible to produce a gimbaling conductor configuration in which torsional beams **360** and **352a** are parallel to each other.

[0167] The gimbaling conductor structure shown in FIG. 27A is fundamentally different from the previously described gimbals because, here, gimbaling movement is facilitated by hinges instead of by torsional beams. In FIG. 27A, flexure **380** includes conductors **382** and **384**. Moving toward the distal ends of conductors **382** and **384**, roll-permissive gimbal regions **386** and **388** are defined. Nearer the distal ends, pitch-permissive hinge regions **390** and **392** are defined. FIG. 27B illustrates the distal end region of flexure **395** which includes the gimbaling conductor structure **380** of FIG. 27A, with the addition of top stiffening layers **394**, **396** and **398**. Stiffeners **394**, **396** and **398** stiffen all areas of the conductors except for isolated hinge regions **386**, **388**, **390** and **392**.

[0168] This hinging gimbal configuration provides several important advantages. First, it can be made smaller (less width required) compared to the gimbal configurations which employ torsional beams, and this allows more of the disk surface, at the inner diameter, to be used for recording data since less pole-to-hub clearance is required. Second, a considerable amount of design flexibility is achieved with roll-permissive hinges **386** and **388** which can be positioned practically anywhere along the length of the flexure.

[0169] FIGS. 28A-30 illustrate another type of flexure which includes what may be thought of as a gimbal, but which differs from previous embodiments principally in that roll flexibility is achieved by the flexure body itself (i.e., by a “torsionally compliant beam”) rather than by torsional beams or hinges, as in previously described gimbals. Three torsionally compliant beams are illustrated. In FIGS. 28A and 28B, a torsionally compliant beam without a pitch gimbaling mechanism, is illustrated. In FIGS. 29A and 29B, a torsionally compliant beam is equipped with pitch-permissive torsional beams in the distal end of the flexure. In FIG. 30, a torsionally compliant beam with pitch-permissive hinges, is shown.

[0170] The first torsionally compliant beam, or flexure, described is shown in FIGS. 28A and 28B. Torsionally compliant flexure **400**, from top view, includes three principal portions, namely, base portion **401**, neck portion (also referred to as a “torsional compliance portion”) **402** and head portion **403**. In a preferred embodiment, base portion **401** has a width W1 of 60-mils. Neck portion **402** has a

width W2 of 20-mils. Head portion **403** has a width W3 of 40-mils. Conductors **404a** and **404b** (dashed lines in FIG. 28A) are adhesively bonded to overlying stiffeners **405a** and **405b**. A hinge region **406** is defined by internal edges of stiffeners of **405a** and **405b**. Three contact pads **407a**, **407b** and **407c** are linearly arranged along the trailing edge of transducer chip **408** which is bonded via solder structures **409a** and **409b** to the bottom sides of conductors **404a** and **404b**. Centrally located contact pad **407b** contains the transducer pole. Only two of the three pads are necessary for the flexure to exhibit torsional compliance. For example, the central pad could be eliminated and the pole could be located in either one of the pads **407a** and **407c**. If the pole is located in one of the off-center pads, it is preferable for the pole to be located in the outside pad, i.e., the side of the chip which is closest to the outer perimeter of the disk, in order to maximize the amount of usable space on the disk. Alternatively, a pole can be located in each of the contact pads **407a** and **407c**. The two poles can be used alternately or selectively depending upon the particular situation. Flexure/transducer **400** is shown with two conductors. However, it is apparent that a similar torsionally compliant flexure design employing four or more conductors can be easily designed and fabricated.

[0171] A torsionally compliant beam must include the following interrelated features: (1) the neck portion of the beam must be sufficiently torsionally soft to permit a desired range of roll movement of the head portion while maintaining sufficient lateral rigidity; (2) there must be at least two laterally-spaced contact pad points underneath the head portion of the flexure; (3) there must be sufficient load applied to the head portion so that a line of interfacial contact between the contact pad points and the surface of the disk is maintained despite external irregularities or aberrations which cause torsional flexing of the neck portion of the beam; and (4) the beam must exhibit sufficient lateral (anti-yaw) stability. Generally, as the distance between the laterally spaced contact points increases, less load is required in order to permit a desired degree of roll movement. Preferably, a torsionally compliant beam is sufficiently soft to permit plus or minus about 0.2° of roll under a total contact load of 300-mg. or less.

[0172] Note that flexure **400** is a gimbaling beam only in the sense that it permits roll motion of the transducer chip. Flexure **400** does not include any pitch gimbaling mechanism. The torsionally compliant beams illustrated in FIGS. 29A-30 are similar to flexure **400**, except they additionally include pitch gimbaling mechanisms.

[0173] The second torsionally compliant beam illustrated is shown in FIGS. 29A and 29B. Flexure **410** includes load-bearing conductors **412** and **414** which are separated from each other and extend the entire length of the flexure body. Importantly, the distal ends of conductors **412** and **414** are configured cooperatively to provide pitch gimbaling. Parallel distal central regions **418a** and **418b** of conductors **412** and **414** form, collectively, a platform **418** for mounting transducer chip **419**. Stiffeners **420**, **422** and **424** are laminated by adhesive (not shown), to the top sides of conductors **412** and **414**. Stiffener **424**, laminated to the top side of platform **418**, leaves exposed torsional beams **430a** and **430b** which allow a selected range of pitch gimbaling of transducer chip **419**. A triangular configuration of pads is employed on the working side of transducer chip **419**. One

pad is located near the center of the trailing edge of chip **419**. The other two pads are located at opposite rear corners of the leading edge of the chip. Similar to previously described gimbal designs, the three pad configuration defines an interfacial contact plane between the transducer chip and the surface of the recording medium.

[0174] Importantly, for a given selected material, intermediate neck portion **432** of flexure **410** is dimensioned (width, length and thickness) relative to the distance between laterally spaced contact pads on the bottom side of transducer chip **419**, and the amount of load applied to chip **419**, so that the neck portion is sufficiently torsionally soft to allow a desired range of roll movement of the transducer-carrying platform, while maintaining the plane of interfacial contact between the contact pads and the disk surface so that a desired range of torsional flexibility (typically 0.2° to 2.0°) for the transducer-carrying platform is permitted. Ideally, the beam is sufficiently torsionally soft to allow the transducer chip to roll approximately plus or minus one degree from applied moment due to the load. For example, flexure **410** has the following specifications: the load is approximately 300- to 350-milligrams; the width of the neck portion **432** of the beam is approximately 20-mils.; the length of the beam from proximal hinge to its distal tip is approximately 350-mils.; and the transducer chip **419** is 40-mils. by 40-mils.

[0175] The flexure **440**, shown in FIG. 30, is essentially the same as torsionally compliant beam **410**, except that a pitch gimbaling movement is permitted by hinges **442** and **444** instead of by torsional beams.

[0176] FIGS. 31-34C illustrate another set of embodiments of the invention, referred to as "dual-cantilever" flexures. In these embodiments, also referred to as disk read/write structures, beams are stacked and spaced from each other by spacers located at each end. The overall dual-cantilever configuration may be referred to as a "parallelogram articulation substructure". Analogous to a "four-bar linkage", the flexure can be flexed without significantly altering the angular relationship between the transducer mounted on the distal end and the surface of a recording medium. Dual-cantilever flexure **460**, as illustrated in FIG. 31, has two sets of conductors and four hinges. However, the dual-cantilever concept could also be implemented in a flexure with one pair of conductors and/or no hinges. Flexure **460** includes a top layer of side-by-side spaced conductors **462** and **464** which are laminated by adhesive, as previously described, to stiffeners **466**, **468** and **469**, with gaps **470a** and **471a** defining proximal and distal hinge regions, respectively. Stiffeners **466** and **469** are mounted on top of spacers **472** and **474**, which in turn are mounted on top of stiffeners **476** and **477** on opposite sides of stiffener **478**. Stiffener **476** is separated from stiffener **478** by a gap **470b** which defines a second proximal hinge region in addition to **470a**. Similarly, stiffener **478** and **477** are separated by a gap **471b** which defines a second distal hinge region in addition to **471a**. Stiffeners **476**, **477** and **478** are laminated on top of conductors **480** and **482**. The distal ends of conductors **480** and **482** support and are mounted on top of transducer chip **484**. FIG. 32 shows a perspective view of flexure **460**, assembled.

[0177] FIG. 33 shows the unloaded U (solid lines) and loaded L (dash-dot lines) positions of flexure **460** relative to disk **490**. Note that flexure **460** is pre-bent in its unloaded

position, with most (ideally all) of the bending occurring in hinge regions **470** and **471**. A notable feature of the dual-cantilever design is that equal and opposite bending occurs toward opposite ends of the flexure. Accordingly, as shown in **FIG. 33**, pre-bends in proximal hinge regions **470a** and **470b** are oppositely matched by pre-bends in distal hinge regions **471a** and **471b**, respectively, so that transducer chip **484** maintains a parallel relationship with disk **490** as it moves from its unloaded to its loaded position. As shown in **FIG. 33**, by pre-bending a dual-cantilever flexure, an extremely close spacing between flexure mount **491** and disk **490** is permitted.

[0178] **FIGS. 34A-34C** illustrate a modified dual-cantilever flexure which does not have any stiffeners, hinges or pre-bends. Thus, it is apparent that the dual-cantilever concept can be practiced beneficially in an unhinged (and non-pre-bent) flexure because one of the main reasons to use a proximal hinge, i.e., minimization of the angular constant of the distal end, is substantially achieved by the dual-cantilever linkage itself. In **FIG. 34A**, flexure **500** includes top layer conductors **502** and **504** mounted on top of spacers **506** and **508**, on top of conductors **510** and **512**. It is necessary to provide electrical connection from the top layer conductors, for example, **502** and **504**, to transducer **514** which is mounted on the bottom side of the distal ends of conductors **510** and **512**. **FIG. 34B** shows a perspective view of flexure **500**, assembled.

[0179] **FIG. 34C** shows a side view of flexure **500** in its unloaded U (dash-dot lines) and loaded L (solid lines) positions, relative to disk **518**.

[0180] The dual-cantilever concept can also be embodied in flexure designs with more or less than four conductors. It is also possible to isolate all of the conductors in either of the top and bottom layers. It is sometimes preferable to isolate all of the conductors in the bottom layer because the distal ends of the bottom layer conductors are in better position for electrical connection to the transducer chip. For example, **FIG. 35** shows a dual-cantilever transducer/flexure **520** including top beam member **521** spaced from conductors **522a** and **522b** by spacers **523a** and **523b** located near the proximal and distal ends of the flexure, respectively. Transducer chip **524** is mounted on the bottom sides of the distal ends of conductors **522a** and **522b**.

[0181] Still another dual-cantilever embodiment **526**, as shown in **FIG. 36A**, includes two conductors **527a** and **527b**, each conductor extending continuously over either the top or bottom layer of flexure **526**. Near the proximal end of the beam, conductors **527a** and **527b** are separated by spacer **528**. A transducer chip **529a** is mounted to the distal end of the beam in an "on-end" or vertical orientation. As shown in **FIG. 36B**, chip **529a** is bound to conductors **527a** and **527b** by conductive epoxy bonds **529c** and **529d**, thus eliminating the need for an additional spacer at the distal end of the beam. Transducer chip **529** is mounted on the bottom side of the distal end of conductor **527b**.

[0182] **FIG. 37A** illustrates a flexure mounting device which contacts and follows the surface of the disk, thereby eliminating the need for a pitch gimbal in the flexure. The device includes mount arm **532** attached to pad **534** which contacts and follows the surface of relatively moving disk **536**. Flexure **538** is attached to mount arm **532**, and supports, at its distal end, transducer chip **540** which contacts

the surface of disk **536** via contact pad **542**. Assuming spacer pad **534** maintains contact with disk **536**, the height point **544** where the proximal end of flexure **538** is mounted, is maintained constant. By mounting flexure **538** on a mounting device which follows the contours of the disk, the need for pitch gimbaling is eliminated.

[0183] The transducer/flexure designs illustrated in **FIGS. 37B and 37C** relate to the mounting structure shown in **FIG. 37A** in the sense that contact pads are located on separate structures which are allowed a range of articulation movement with respect to each other. Generally, this important feature of the invention makes possible gimbal designs in which the contact pads are spread out further from each other—resulting in greater surface accommodating stability. This is a contrast to the pad configurations previously described in which the distance between the pads has been generally limited by the size of the transducer chip.

[0184] In **FIG. 37B**, transducer/flexure **545**, near its distal end **546a**, has a hole **546b** for mounting, and a bonding window **546c**. A proximal hinge region **546d** exposes conductors **546e** and **546f** which are also exposed through bonding window **546c**. Moving toward the distal end of transducer/flexure **545**, in an intermediate region, stiffeners **546g** and **546h** are laminated on top of conductors **546d** and **546f**, respectively. Conductors **546e** and **546f** are again exposed in a second hinge region defined by spaces between stiffeners **546g**, **546h** and stiffener **546k**. On the bottom side of the flexure portion stiffened by stiffener **546k**, contact pads **546l** and **546m** are positioned near opposite lateral edges of the portion. Conductors **546e** and **546f** are again exposed in a third hinge region defined by a space between stiffener **546k** and stiffener **546p**. Underneath and toward the distal end of stiffener **546p**, transducer **546q** is mounted. A contact pad **546r** is located on the bottom side of transducer **546g**, near its trailing edge. Transducer/flexure **545** can be viewed as being made up of plural, articulated beam portions.

[0185] In transducer/flexure **545**, the conductors in the second hinge region and laterally spaced contact pads **546l** and **546m**, collectively provide for gimbaling movement of the transducer chip independent from the proximal end region of the flexure body. Pitch movement of transducer chip **546q** is made possible by the conductor hinges in the third hinge region between the laterally spaced contact pads and the centrally located pad at the distal tip of the transducer chip.

[0186] The transducer/flexure shown in **FIG. 37C** is similar to the one shown in **FIG. 37B**. Transducer/flexure **547**, near its proximal end **548a**, has a hole **548b** for mounting alignment, and bonding windows **548c** and **548d**. Conductors **548e**, **548f**, **548g** and **548h** are exposed in bonding windows **548c** and **548d**, respectively, and in a first hinge region **549a**. Moving distally along the flexure, stiffener **548i** is laminated on top of conductors **548e** and **548f**, and stiffener **548i** is laminated on top of conductors **548g** and **548h**. The conductors are again exposed in a second hinge region **549b** which is defined by the spaces between stiffeners **548i**, **548i** and stiffener **548k**. On the bottom side of the flexure region stiffened by stiffener **548k**, are laterally spaced contact pads **548l** and **548m** (shown in dashed lines). Continuing to move toward the distal end of the flexure, the conductors are again exposed in a third hinge region **549c**,

defined by the space between stiffener **548k** and **548n**. At the distal end of the flexure, transducer chip **548o** (shown in dashed lines) is mounted on the bottom side of the flexure. A pole containing contact pad **548p** (shown in dashed lines) is located on the bottom side of transducer chip **548o**.

[0187] Each of the embodiments shown in FIGS. **37A-37C**, illustrates important modification options relating to contact pad configurations. First, these embodiments (FIGS. **37A-37C**) show that the contact pads do not have to be formed on the chip itself, as they are in the previously described transducer/flexure designs. Second, it is possible to position one or more of the contact pads on beam portions of the flexure which articulate independently from the flexure portion on which the transducer is mounted. For example, in a gimbal such as the one shown in FIGS. **13-15C**, the laterally-spaced contact pads on the leading edge of chip **210** could be replaced on the bottom side of the roll frame stiffened by stiffener **220**. These principles make it possible to increase greatly the longitudinal and lateral distances between the pads within constraints due to size and disk waviness. As already noted, increasing the distances between the pads improves the operable stability of the flexure. Increase in the distance between the pads also makes it possible for the gimbal to perform under a lighter load. Minimizing the load, in turn, is important for the purpose of minimizing wear, reducing function, and lowering the probability of head and/or disk crash events.

[0188] FIGS. **38A-38C** illustrate two flexure mounting systems. The mounting system illustrated in FIGS. **38B** and **38C** employ a dual-cantilever structure resulting in closer disk-to-disk spacing in comparison to previous flexure mounting systems, such as the one illustrated in FIG. **38A**. The flexure mounting system **550**, shown in FIG. **38A**, includes E block **552** supporting flexure mounts **554a**, **554b**, **554c** and **554d**, which in turn hold flexures **556a**, **556b**, **556c** and **556d**, respectively. The flexures are supported in contacting relationship with opposing surfaces of disks **558a** and **558b**. Because of the relatively rigid relationship between E block **552** and mounts **554a-554d**, in order to accommodate mounting and operating tolerances, a relative large spacing distance **560** must be maintained between the disks. In contrast, the flexure mounting system **570**, as shown in FIG. **38B**, permits significantly closer disk-to-disk spacing, by using a dual-cantilever in the mounting structure. In flexure mounting system **570**, E block **572** supports dual-cantilever mounting structure **574** which has an elongate distal end **576** connected to flexure **578**, which end supports transducer chip **580** in contact with the surface of disk **582**. Each of the other flexures in the system shown in FIG. **38B**, is similarly mounted. Dual-cantilever structure **574** allows relative movement between E block **572** and disk **582**, while maintaining a parallel relationship between its elongate distal end **576** and the surface of disk **582**. Accordingly, requisite disk-to-disk spacing **584** is greatly reduced relative to disk-to-disk space **560** in the prior system illustrated in FIG. **38A**.

[0189] FIG. **38C** is a magnified view of a single flexure mounting device from FIG. **38B**. The elongate distal end **576** of dual-cantilever structure **574** supports pad **586** in a contacting relationship with the surface of disk **582**. The proximal end of flexure **578** is attached to dual-cantilever structure distal end **576**. By employing dual-cantilever structure **574** and disk-contacting pad **586**, dual-cantilever distal

end **576** is maintained in a parallel relationship to the surface of disk **582**, and at a constant height above the disk. In addition to allowing closer disk-to-disk spacing, the design shown in FIG. **38C** also substantially eliminates the need for pitch gimbaling analogous to the system illustrated in FIG. **37A**.

[0190] Another aspect of the present invention relates to the goal of simplifying the process of mounting a flexure on an E block, and more specifically, providing an easy way of connecting the flexure electrically to a flex cable. FIGS. **39A-39C** illustrate a flexure mounting structure which is versatile in the sense that it can be easily electrically connected to a mother flex cable in either an upside or a downside orientation. Nut-plate/flexure structure **587a**, as shown in FIG. **39A**, includes a flexure **588a** which may take the form of any of the flexures previously described in this application, except for its different conductor structure. Nut-plate **588b** is welded by spots **588c** to a stiffener layer which is laminated on top of conductors **589a** and **589b** toward the proximal end of flexure **588a**. Conductors **589a** and **589b** run from the transducer chip through the flexure where conductor **589a** passes through the center region of the flexure and conductor **589b** extends along both sides of the intermediate portion of flexure **588a**. Conductor **589b** then passes under nut-plate **588b**, and eventually extends in opposite lateral directions along paths leading to laterally opposite, proximally located tabs **588aa** and **588bb**. Similarly, centrally extending conductor **589a** extends under nut-plate **588b** and eventually splits into separate laterally opposite directions on paths which end in tabs **588aa** and **588bb**. On tab **588aa** conductors **589a** and **589b** are exposed on the bottom side, and therefore are not visible in the view shown (dashed lines). Conversely, conductors **589a** and **589b** are exposed on the top side of tab **588bb**. Thus, if nut-plate/flexure **587a** is mounted under an E block arm, electrical connection to the flex cable is accomplished by bending tab **588bb** up so that the conductors contact the flex cable conductors. Alternatively, if nut-plate/flexure **587a** is mounted on top of an E block arm, electrical connection is accomplished by bending tab **588aa** down so that conductors **589a** and **589b** contact the conductors in the flex cable. FIG. **39B** shows four nut-plate/flexures, each one configured as shown in FIG. **39A**, mounted on an E block. Nut-plate/flexure **587a** is electrically connected to a flex cable **588d** via conductor contact tab **589bb**. Nut-plate/flexure **587b** is electrically connected to flex cable **588d** through conductor contact tab **589cc**. Nut-plate/flexure **587c** is electrically connected to flex cable **588d** through conductor contact tab **589dd**. Nut-plate/flexure **587d** is electrically connected to flex cable **588d** through conductor contact tab **589ee**.

[0191] FIG. **39C** shows a modified conductor configuration that results in lateral tabs which facilitate easy upside/downside electrical connection to a flex cable. Nut-plate/flexure **588e** includes conductors **589i** and **589j** which extend from a gimballed transducer mounted near the distal end of the flexure, through the flexure body, under the nut-plate, into semi-circular conductor contact tab **589ff** then to conductor contact pad **589gg**. On tab **589ff**, conductors **589i** and **589j** are upwardly exposed. On pad **589gg**, conductors **589i** and **589j** are downwardly exposed, and therefore not visible in the view shown (dashed lines).

[0192] The flexures previously described are generally designed to operate under a load in the range of 30- to 300-, and preferably 35- to 70-milligrams. It is important to minimize the load exerted on the flexure during operation in order to minimize the rates of head and disk wear and to lower frictional power consumption. However, for those flexures which include a gimbal, it is necessary to apply a load which is great enough to maintain contact between the transducer chip contact pads and the disk surface, through the desired ranges of pitch and roll movement. It is generally possible to upsize and downsize the flexure designs described in this application, for use under different applied loads. For example, the load which is required for adequate gimbaling of a given flexure design, can be decreased by lengthening and/or thinning the dimensions of gimbal articulator structures, i.e., hinges or torsional beams.

[0193] FIGS. 40A-40C illustrate a flexure which is designed to operate under a load of approximately 35- to 70-milligrams. Beginning near the proximal end of flexure 590, a hole 591a is provided for mounting alignment. A window 591b exposes conductors 592a and 592b for electrical bonding. Within proximal hinge region 591c, conductors 592a and 592b are again visible. The primary structural components of hinge region 591c are stiffener straps 591d and 591e which are integral parts of stiffener 591f. Approaching the distal end of flexure 590, distal hinge region 591g is made up of lateral edge portions of conductors 592a and 592b. A gimbal 591h is provided near the distal end of flexure 590 for mounting a transducer and for facilitating movement of the transducer independent from the main body of flexure 590. Three separate stiffeners 591i, 591j and 591k define gimbal articulators which are shown in more detail in FIGS. 40B and 40C. Dimensions of flexure 590 are as follows:

[0194] AA=0.060-inches

[0195] BB=0.455-inches

[0196] CC=0.030-inches

[0197] DD=0.010-inches

[0198] EE=0.350-inches

[0199] FF=0.080-inches

[0200] FIG. 40B illustrates an isolated top view of the conductors 592a and 592b. The conductors are separately shaded in order to emphasize their separate paths. Stiffening layers 592c and 592d are co-planar with conductors 592a and 592b, but are separate from the conductors so they do not function as conductors in flexure 590. Conductor 592a extends to the distal tip of flexure 590, then passes toward the transducer chip through torsional beam 592e, then through hinge 592f, finally ending in a transducer mounting platform 592g. Similarly, conductor 592b passes through torsional beam 592h, then through hinge 592i, and ends in a transducer mounting platform 592j.

[0201] FIG. 40C shows a magnified view of the assembled gimbal in flexure 590. As previously described, stiffeners 591i, 591j and 591k expose and define gimbal articulators, namely, roll-permissive torsional beams 592e and 592h, and pitch-permissive hinges 592f and 592i. Shock-resistant tabs 594a, 594b, 594c and 594d extend across the gap between stiffeners 591i and 591k. These tabs limit the distance or extent to which the transducer-carrying

central region of the gimbal can move upward along the Z axis out of the plane containing the roll structure stiffened by stiffener 591j. Similarly, tabs 595a, 595b, 595c and 595d extend across the gap between stiffeners 591i and 591j, thereby limiting the extent to which the roll frame can move upward along the Z axis above the plane containing the main body of the flexure. The primary purpose of the tabs is to limit the movement of gimbal parts in a high-shock situation.

[0202] Miniature reservoirs for containing dampening material in and around the gimbal region are also defined. Each reservoir is typically formed by making semi-circular cuts on opposite edges of stiffeners near a gap between gimbal parts. For example, an outer organization of reservoirs 597a, 597b, 597c and 597d facilitate deposition of a damping material through a syringe, for example, damping material 598 in reservoir 597a, creating a bridge across the gap between stiffener 591i and 591j. Two more damping material reservoirs 599a and 599b are located across gaps between stiffeners 591j and 591k on opposite sides of stiffener 591k. Hole 599c in the center of stiffener 591k is provided to permit application of adhesive for the purpose of bonding the chip to the suspension. Preferred dimensions in the gimbal region are as follows:

[0203] GG=0.0028-inches

[0204] HH=0.007-inches

[0205] II=0.024-inches

[0206] JJ=0.002-inches

[0207] KK=0.020-inches

[0208] LL=0.040-inches

[0209] MM=0.002-inches

[0210] NN=0.002-inches

[0211] OO=0.002-inches

[0212] conductor thickness=0.0004-inches

[0213] stiffener thickness=0.0008-inches

[0214] It should be noted with respect to flexure 590, as well as all of the other flexures previously described in which a hinge is located near the distal end of the flexure, that it is sometimes preferred to replace the hinge with a pre-bend. Such a bend is in the range of approximately 1°-4° around an axis parallel to the X axis (rotation of the distal end of the flexure upward out of the plane containing the flexure body). Fabricating a bend near the distal tip of the flexure is an extra manufacturing step in comparison to a process for manufacturing a flat flexure with a proximal hinge. However, a proximal bend is sometimes preferred over a proximal hinge because it improves vibrational stability and is more robust to shock. For example, FIG. 40D shows schematically a side view of flexure 599d which includes a main body portion 599e and a distal end portion 599f. The distal end portion 599f is slightly bent at point 599g with respect to main body portion 599e. Angle α , i.e., the degree of pre-bending is approximately 1-4°.

Methods of Production

[0215] Various combinations of machining and chemical etching steps may be used to construct flexures of the present invention.

EXAMPLE 1

[0216] Multiple sets of flexure layers are cut out of single sheets. For example, FIG. 41 shows a sheet 600 with four quadrants 602, 604, 606 and 608. A set of laminated flexures is produced simultaneously in each quadrant. The following figures and description focus on only a single quadrant.

[0217] A 1-mil. layer of stainless steel is mechanically (laser) cut out in the pattern shown in FIG. 42. Cut-out section 610 defines the hinge, and cut-outs such as 612 form rectangular windows for wire bonding.

[0218] A second sheet of adhesive is cut with the same pattern as shown in FIG. 42. If the adhesive is attached to the 1-mil. stainless steel layer prior to cutting, both layers can be cut simultaneously.

[0219] A conductive layer is mechanically cut out of a 0.5-mil. thick stainless steel sheet, according to the pattern 613 shown in FIG. 43, so that all conductors are electrically isolated after the final cut is made, as explained below. The material is then cleaned and gold plated on both sides of the sheet in region PP.

[0220] The alignment holes are then used to align the layers on tooling pins. The layers are pressed to specified loads and heated in an oven to promote curing of the adhesive.

[0221] The laminant is cut with a laser to define the beam shape 614 as shown in FIG. 44. The cut either defines individual beams 614 or "combs" 616 of beams.

[0222] FIG. 45 shows a composite of all cuts.

[0223] FIG. 46 shows a final beam, essentially corresponding to the flexure illustrated in FIGS. 2 and 2B.

[0224] The flexure shown in FIG. 46 has the following dimensions:

[0225] A=40 mils.

[0226] B=20 mils.

[0227] C=350 mils.

[0228] D=390 mils.

[0229] E=430 mils.

[0230] F=24 mils.

[0231] G=10 mils.

[0232] H=12 mils.

[0233] I=21 mils.

[0234] J=44 mils.

[0235] K=60 mils.

EXAMPLE 2

[0236] The second manufacturing example employs chemical etching and/or laser cutting steps. Three sets of conductive layers are cut out from areas 330, 332 and 334 of one sheet 336, as shown in FIG. 47. The following description and drawings refer to the production of a single set of flexures from area 330. Alternatively, a continuous sheet of adhesive can be applied, then cut out by plasma etching after the conductor and stiffener layers are laminated.

[0237] A 0.5-mil. thick stainless steel conductor layer is patterned as shown in FIG. 48. Pattern 340 is cut out either by chemical etching or laser cutting. During the production process, conductor pairs remain attached to adjacent conductor pairs by tabs 342. A corresponding 1-mil. thick stainless steel stiffener layer is chemically etched or laser cut according to pattern 343 shown in FIG. 49. Adjacent stiffeners are held together by tabs 344 and 346. An adhesive layer is applied either by stamping or laser cutting.

[0238] A 0.5-mil. thick layer of gold is plated onto the conductors. The gold may be plated onto the entire conductor surface (preferred for stainless steel) or may be confined to the electrical bonding regions (preferred for beryllium copper).

[0239] The layers are aligned and bonded under temperature and pressure.

[0240] Finally, individual flexures are separated from each other by mechanically shearing or laser cutting tabs 342, 344 and 346.

[0241] Other methods of producing laminant suspensions such as the ones disclosed in U.S. Pat. No. 4,991,045 and No. 5,187,625 (both are incorporated here by reference) have been developed by Hutchinson Technology Inc. of Hutchinson, Minn. and are generally applicable to the flexures disclosed in this application.

EXAMPLE 3

[0242] The following technique is used to attach the transducer chip.

[0243] Solder paste is applied with a stencil to the chip or beam (conductors).

[0244] The beam and the chip are aligned and the solder is heated to its melting point either locally with hot air, laser or infrared heating, or placed in an oven.

EXAMPLE 4

[0245] Another method for attaching the transducer chip involves laser soldering. First, tin is deposited on gold bonding pads on the chip. Second, a laser is used to heat the gold and tin through small holes (example, holes 90 in FIGS. 2 and 3A) in the metal (stiffener) or by heating the metal directly. The tin and gold melt to form a eutectic bond.

EXAMPLE 5

[0246] The following process is used to attach a damper for the purpose of attenuating vibrations. Damping material can be applied either before or after patterning.

[0247] In a pre-patterning technique, damper (viscoelastic polymer on constraining layer) is stamped or cut with a laser to define the shape. Each damper is then aligned individually and then applied to each beam.

[0248] In a post-patterning process, a square of damping material with constraining layer is applied to the beam or comb without precise alignment. A laser is then used to trim the shape of the damping material to be slightly larger than the beam shape.

EXAMPLE 6

[0249] The following techniques are used to lap a single pad on a chip, for example, 97 in FIGS. 3B and 3C.

[0250] First, the beams are made on a comb with relatively long fingers. The comb is placed in a “lapper/tester” machine which loads the beam onto a rough disk for lapping. Electrical connection is made through the metal in these fingers (an extension of the beam conductors).

[0251] The machine individually twists the comb fingers and uses the magnetic signal as a lapping stop indicator to achieve “roll” facets.

[0252] Pitch facets are achieved by changing the Z-height and thereby changing the angle at the beam tip.

[0253] Magnetic performance may also be tested in the process.

EXAMPLE 7

[0254] The following technique is used for lapping a three-pad chip, such as the one employed in the gimbaling flexures described above. Since the gimbal compensates for static tolerances, only a flat lap is required to achieve full signal quickly in the drive. Therefore, a shorter, simpler comb may be used with a simpler lapping machine. This machine loads the beams to a given Z-height, exposing the pole and testing.

[0255] It is also possible to lap the chip pad prior to attaching the chip to the beam.

[0256] **FIGS. 50A and 50B** schematically illustrate modified forms of transducer chips. In contrast to the rectangular transducer chips previously described, the chips shown in **FIGS. 50A and 50B** have different shapes for the purposes of: (a) maximizing the lateral and longitudinal distances between contact pads; (b) minimizing the weight of the transducer chip; and (c) maximizing the efficient use of materials in the chip-making process. The T-shaped and triangle-shaped transducers, as shown in **FIGS. 50A and 50B**, respectively, are particularly useful chip designs where a tri-pad arrangement is formed on the bottom of the chip for use in a gimballed, disk-contacting transducer/flexure. In **FIG. 50A**, T-shaped chip **400** has contact pads **402a**, **402b** and **402c** arranged in a triangular configuration. Similarly, in **FIG. 50B**, triangular chip **410** has three contact pads **412a**, **412b** and **412c**, again arranged in a triangular configuration. The shapes and dimensions of the chip are also dictated by the particular coil structure which is typically embedded in the chip.

[0257] Although numerous embodiments of the invention have been described in detail above, it is apparent that many other modifications are enabled by the disclosure and encompassed in spirit and scope by the claims set forth below. For example, while most all of the embodiments specifically described above are transducer/flexures which are designed to operate in contact with the surface of a medium, it is apparent that many of the principles of the present invention have application to non-contacting or quasi-contacting transducer/flexures, such as “flying sliders”. Flying sliders do not employ pads such as the ones described in this application, but instead employ rails or

air-bearing pads. However, flying sliders frequently require gimbaling mechanisms, and face many similar mechanical accommodation challenges as do contacting transducer/flexures. The fact that most of the embodiments described in this application are shown with contacting pads, should not be viewed in any way as a limitation on the applicability of the present invention to non-contacting or quasi-contacting head/flexure systems.

[0258] Further, it is important to recall that many of the features of the present invention can be employed to great advantage with mediums other than rigid disks—for example, with drums, floppy disks, tape, etc.

We claim:

1. A disk-drive flexure/conductor structure comprising
 - an elongate flexure body having a distal end including a plurality of conductors spaced from each other and extending along substantially the entire length of the body, and
 - an electromagnetic transducer mounted on the distal end of the flexure body and held in dynamic contact with a recording surface of a magnetic recording medium amid read/write communication with said medium, and wherein each of said conductors has a thickness which is at least about 13% of the total thickness of the body so that the conductors function as load bearing beams at least partially supporting the transducer.
2. A device for storing and retrieving information on a spinning rigid disk comprising:
 - a transducer composed of a plurality of adjoining solid films including a disk-facing projection, a conductive coil inductively coupled to a magnetically permeable core terminating in a pair of tips encased by said projection for concurrent contact and communication with the disk, and
 - an elongated arm attached to said transducer, composed of a plurality of adjoining solid layers and having a length, a width and a thickness with said thickness being substantially less than said width and said width being substantially less than said length, said arm including a plurality of conductive ribbons extending lengthwise, separated widthwise and connected to said coil.
3. The device of claim 2, wherein at least one of said tips is exposed adjacent to the disk.
4. The device of claim 2, wherein said conductive ribbons are disposed on a disk-facing portion of said arm.
5. The device of claim 2, wherein said conductive ribbons are separated from other solid layers of said arm adjacent to said transducer.
6. The disk-drive flexure/conductor structure of claim 2, wherein the thickness of the conductors are at least about 20% of the total thickness of the flexure body.
7. The disk-drive flexure/conductor structure of claim 2, wherein the flexure body has a proximal end opposite from the distal end, the flexure body having two lateral edges which taper inward from the proximal end toward the distal end so that the width of the flexure body near the distal end is less than the width of the flexure body near the proximal end.

8. The disk-drive flexure/conductor structure of claim 1 further comprising a gimbal mechanism connecting the flexure body to the transducer so that the transducer is permitted to move relative to the flexure body during read/write operation on a magnetic recording medium.

9. The disk-drive flexure/conductor structure of claim 1, wherein the flexure body has at least one location along its length where the conductors are the sole load-bearing beams in the flexure body.

10. The disk-drive flexure/conductor structure of claim 9, wherein said location along the length of the flexure body defines a hinge region for permitting controlled movement of the transducer along a Z-axis perpendicular to a recording medium surface.

11. The disk-drive flexure/conductor structure of claim 9, wherein said location is closer to the proximal end of the flexure body than it is to the distal end of the flexure body.

12. The disk-drive flexure/conductor structure of claim 1 wherein the flexure body includes at least one stiffening layer adhesively bonded to the conductors.

13. The disk-drive flexure/conductor structure of claim 10, wherein the flexure body includes stiffening layers adhesively joined to the conductors on opposite sides of the hinge region.

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