

June 3, 1969

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3,447,455

PRINT-HAMMER MOUNT AND FABRICATION METHOD

Filed Sept. 20, 1967

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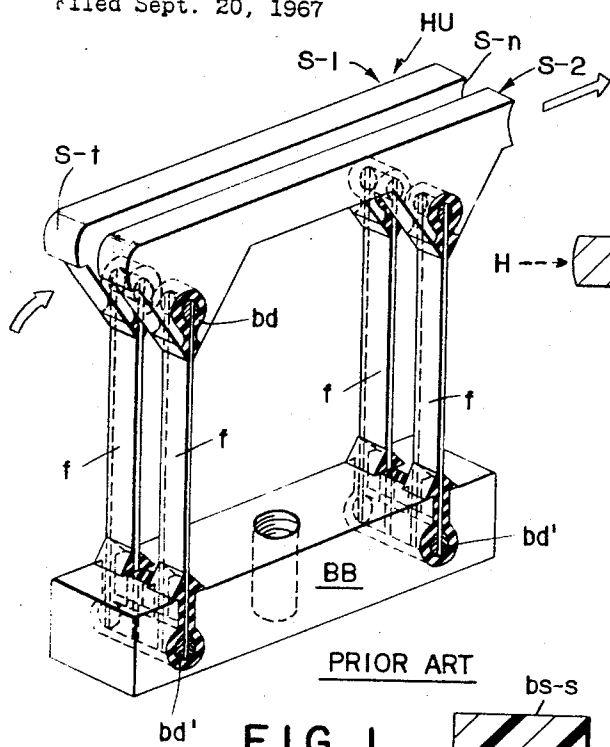


FIG. 1

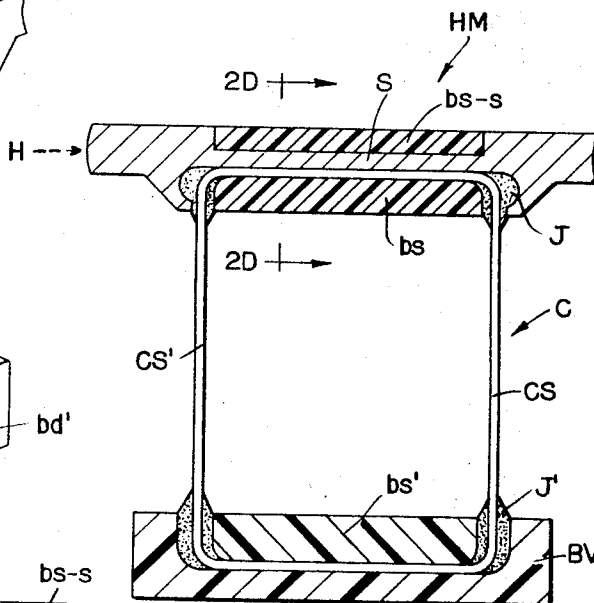


FIG. 2A

FIG. 2D

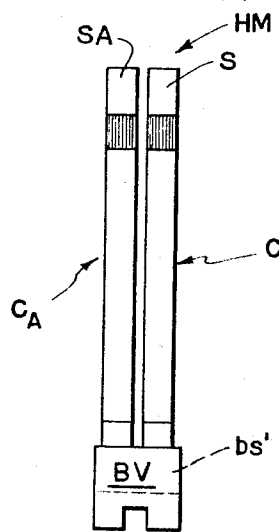
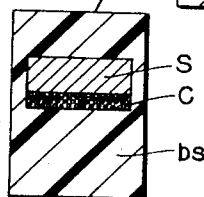


FIG. 2B

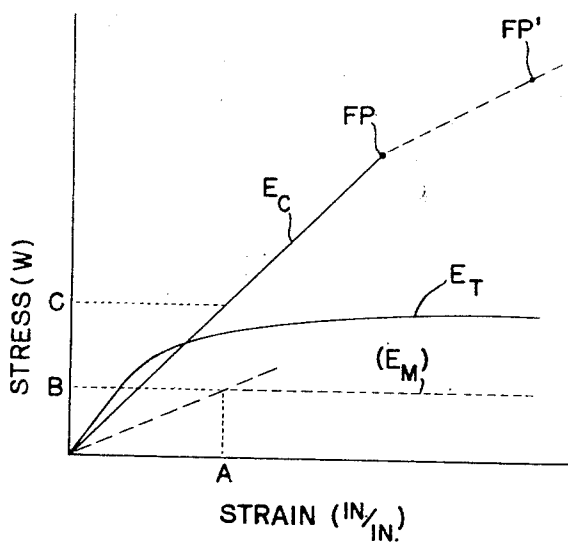


FIG. 2C

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FIG. 3

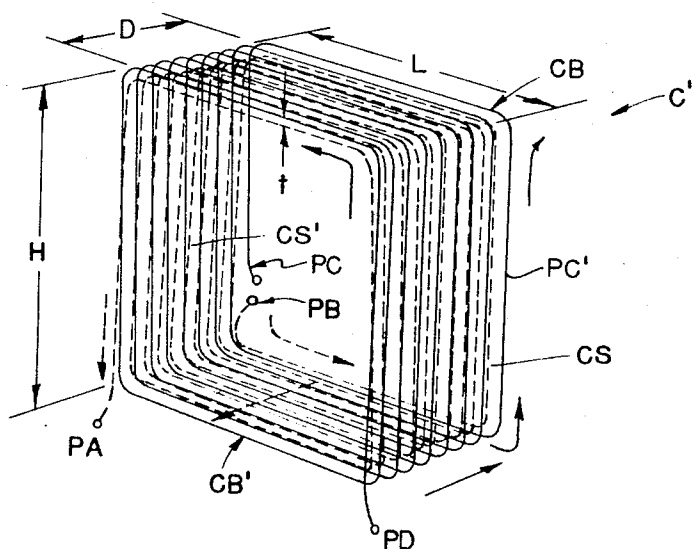


FIG. 4

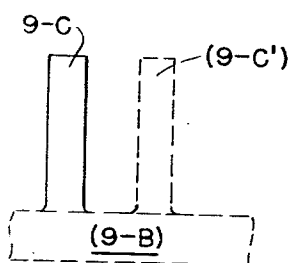
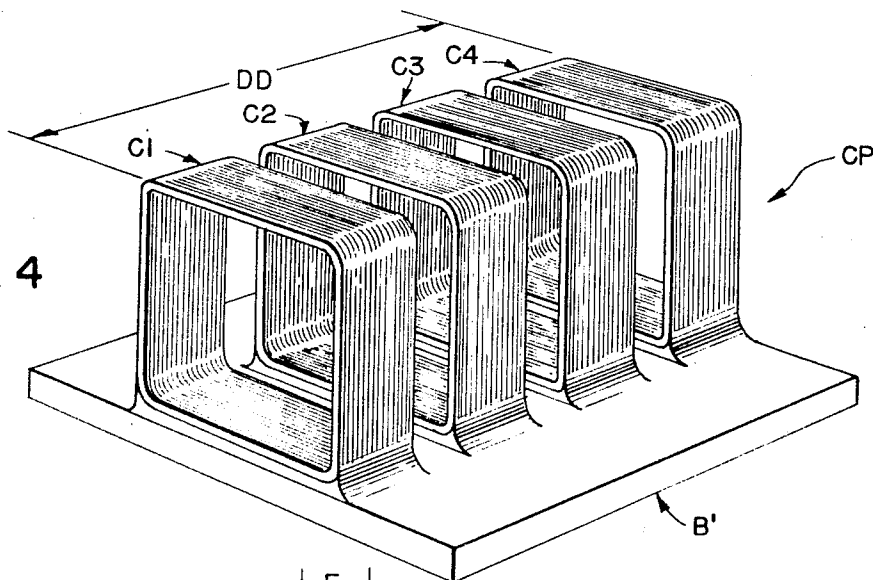


FIG. 8

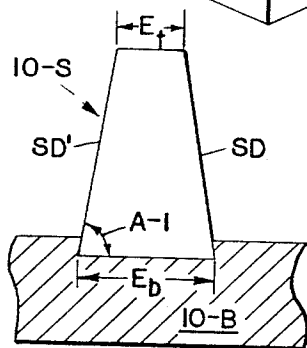


FIG. 9

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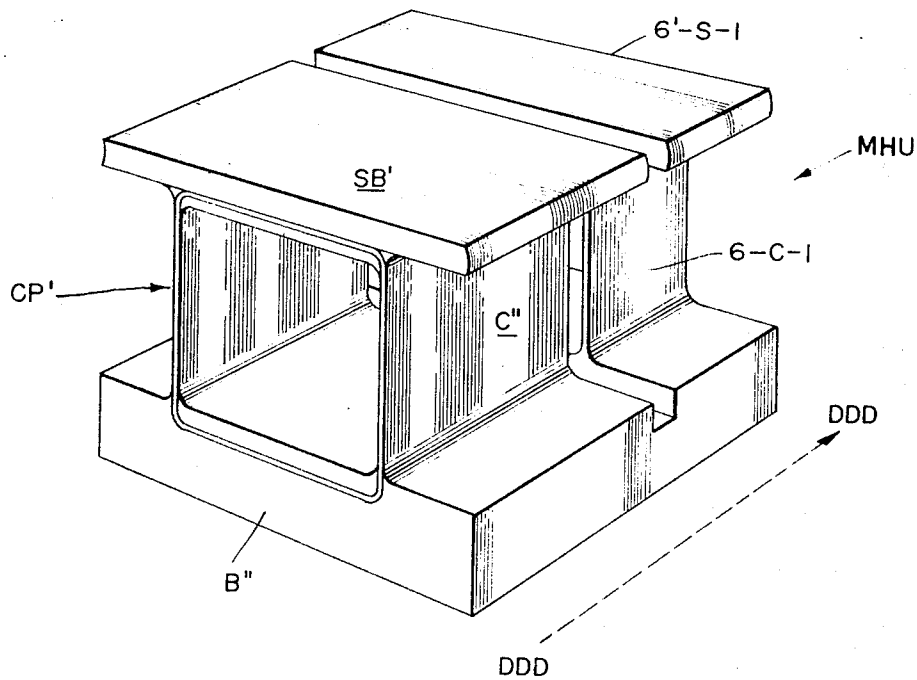
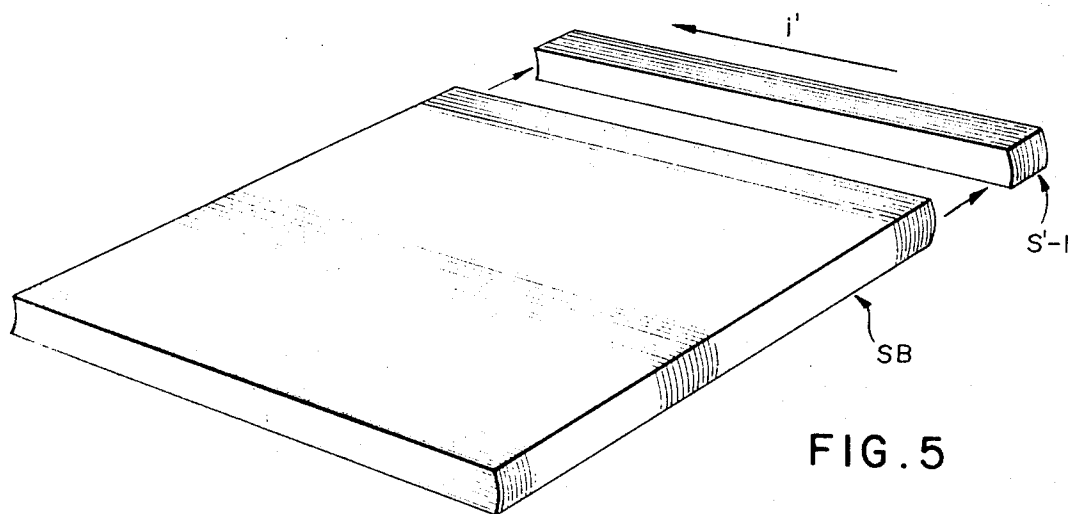
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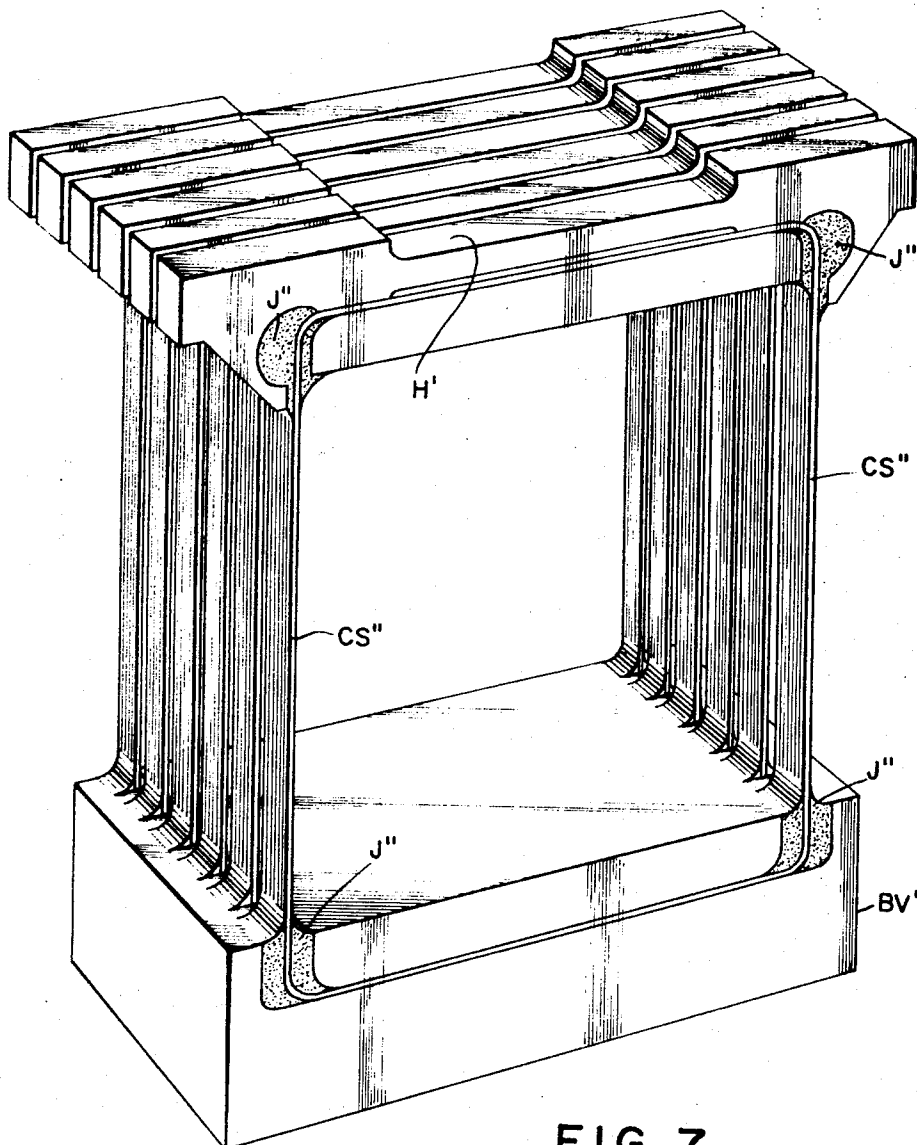


FIG. 7

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PRINT-HAMMER MOUNT AND FABRICATION METHOD

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U.S. Cl. 101—93

6 Claims

ABSTRACT OF THE DISCLOSURE

A pivot flexure mounting arrangement for a reciprocating hammer, or a set of them, together with methods for fabricating them. An embodiment comprises a continuously-wound coil of parallel fibreglass filaments (as a strong, "high-modulus" material), the coil being potted in a compatible resin (the weak, more elastic "binder-material") thus forming a composite coil-mount for pivotably supporting a hammer (set) to be resiliently reciprocated relative the fixed base on which the coil mount is affixed. In a preferred embodiment an associated set of such mounts may be simultaneously formed as an integral multi-coil unit for supporting an aligned set of print-hammers for individual reciprocation. The set of hammers (impact elements) may likewise be so formed together, being sliced from a single composite fibreglass/resin structure. The hammers are preferably epoxy-bonded to the coil mount, the mount preferably being formed in an endless-web configuration.

Problems, invention features

In the art of designing high-speed printers, such as for providing computer print-out, it is conventional today to mount the print hammers as indicated in FIGURE 1 where a double print hammer unit HU is shown somewhat schematically. It will be understood that a plurality of such units is typically arrayed across a printing zone to be operatively adjacent the locus of the print drum and intermediate paper and ribbon material, e.g., about 80 such units for a 160-column printer. Each such unit HU will generally comprise a pair of hammers (slugs) S-1, S-2, each mounted, front and rear, on a pair of pivot flexures *f* in prescribed relation to a fixed base BB; the base being adapted to be located in prescribed relation with the printing locus, as known in the art. Flexure supports *f* are typically joined to their respective slugs S by an elastomeric bond *bd* embedded in a cavity in the slug and are similarly bonded to base BB through a similar elastomeric bond *bd'* embedded in cavities therein. Such flexures *f* support the hammer load to be pivotable in a prescribed (print-impact) direction, while storing and releasing energy under high frequency print-impacting. Thus, as understood in the art, when hammer unit HU and its companion units are properly fixed and aligned along their printing locus, they will be adapted to be impacted, at their tail portion, S-*t*, to drive their print-impacting head portion, S-*n* against the print drum and intermediate forms (as indicated by the arrows). This operation is recognized as imposing high impact, high frequency stresses on these units to the extent that failure of hammer units, and especially their flexure supports, is perhaps probably the most common and troublesome malady of today's high-speed printers. Moreover, this problem exists despite the fussy, expensive fabrication operations typically used to make the hammer units so they will respond quickly enough, will apply a constant impact force, and will keep properly aligned and not fail under hundreds of millions of high-stress cycles. This

is a uniquely-severe flexure environment; no other within contemplation demands such extremely long (high-frequency) cycle-life.

As workers in the art well know, the joining of the mounting flexures *f* to relatively rigid base BB, as well as to slugs S, involves many disagreeable problems. One such problem is maintaining a precise orientation of the slugs relative base BB (so that a slug may be operatively driven in precise alignment against the paper—something critically important for high-speed printers, of course). Such problems have called forth fabrication procedures which are all too complicated, such as arranging the hammer parts in a jig, pouring and molding settable bonding material around them and thereafter curing, etc.—all the while trying to keep them precisely aligned despite curing stresses, shrinkage and the like. It is well-known that such procedures characteristically make it a genuine feat to keep these parts aligned, especially since the bonding materials themselves can introduce distortion (e.g., from shrinkage between the flexure and the bonded member). This problem is greatly amplified, of course, by the stresses imposed by manually handling the units, as is necessary with such fabrication methods. The present invention provides a novel hammer support arrangement involving none of the above problems and providing superior operating characteristics, as well as more fabrication convenience and reliability.

Another difficulty associated with bonding slugs to their supports is that of support-fatigue and breakage. With high-speed printers using the flexure strips *f* of FIGURE 1, for instance, this is an outstanding problem, given the typical extreme slug-actuating forces and high frequency operation. Unless this actuation is quite precisely controlled and over a very long life, the units will not serve satisfactorily with high-speed computer systems. Moreover, such units are uneconomic unless they can be made to be virtually 100% reliable and maintenance-free, since their failure will typically shut down an expensive computer system costing hundreds of dollars per hour. The present invention will be seen to provide an answer to these difficulties in providing a highly reliable mounting arrangement for hammer-slugs and for bonding these in place so as to give improved operation and reliability over a longer life. More particularly, the invention provides such an advantageous mount in the form of a unitary, one-piece coil (such as coil C in FIGURE 2), having a carefully prescribed composite construction and being adapted to be formed as an endless web. Such a coil may readily be intimately bonded, such as with epoxy, to both the hammer slug and the base.

The aforementioned prior art problem of support fatigue and breakage stems, to a great extent, from the materials and fabrication methods heretofore used in fabricating the flexures *f* (FIGURE 1). For instance, flexures *f* are customarily stamped from stock spring steel and thus are especially apt to be "notch sensitive"; that is, apt to have tiny irregularities along their edges which act as "failure sites" liable to induce premature rupture and failure. This problem can be somewhat ameliorated by grinding such edges to be very smooth; however, this is an expensive, fussy procedure and is best avoided, if possible. By contrast, the present invention specifies a two-phase flexure structure (of a reinforced plastic) that confines any such notches (to the surface resins only), that can isolate notches from the bulk of the material and, in sum, is not "notch sensitive" in the aforescribed sense. Thus, the present structure can withstand a great deal more fatigue stress than many high strength metals, while being much simpler and less expensive to fabricate. For instance, where most metals specimens retain only thirty to fifty percent of their

fatigue strength when they are somewhat notched, a glass-reinforced plastic flexure according to the invention can retain about eighty to ninety percent strength under like conditions.

A related fabrication problem with prior art flexures f is "dimensional stability." The expansion and/or shrinkage of steel flexures f is a very common source of production problems and failure during life; especially when these dimensional changes occur in the area of the slug-bond (bd , bd'). The fiber reinforced plastic of the invention is much more stable. This stability is optimized moreover when glass is used as the fiber material, e.g., it appears to give a minimum of water adsorption (as opposed to nylon), assuming that the glass fiber comprises a major portion of the composite flexure bulk. It also has much less mold-shrinkage and cold flow, or creep, (e.g., less than a "pure-plastic" matrix.) A related advantage of such a composite flexure is its comparative freedom from internal, residual stresses induced by manufacturing steps. Such stresses are commonly induced in prior art metal flexures during fabrication, whereas they should never occur with the convenient molding methods for the composite flexures of the invention.

General characteristics

More particularly, I have found that besides using the aforementioned unitary (coil) construction, it is especially advantageous to fabricate hammer (slug) supports to be of composite materials having diverse elastic characteristics. In one form they are made by winding strong, "high-modulus," filaments, such as of fiberglass, to form an endless, multilayered coil and thereafter potting these filaments in a relatively weak, more elastic potting (binding) matrix, such as in a compatible adherent resin. Also, the slug and base elements may be simultaneously bonded. I have found that such a composite construction of "diverse-elasticity" materials can provide a mounting flexure at reasonable cost having strength and elasticity properties that no analogous homogeneous (single-phase) material appears to possess. For instance, potting fiberglass filaments into an (elastic) plastic matrix, yields a support flexure that is unexpectedly advantageous. It appears best that the bulk of this material comprise the high strength (fiberglass) material, dispersing the elastic matrix material (resin) adherently therebetween. The resultant composite structure is able to absorb a loading stress that would easily rupture the weaker plastic (if used above), while dispersing the high strength fibers throughout this matrix and isolating them somewhat this way, prevents minor imperfections in any single fiber from being propagated across the entire structure. As a result, while individual filaments may yield to an applied load, the load will thereupon be redistributed through the elastic matrix to be borne by other filaments in the composite structure. It has been found that the filament material must be considerably stronger than the matrix material, as explained hereinafter.

Structural parameters

The aforementioned fiberglass-plastic material, according to the invention, is preferably wound as a continuous multi-layer coil into a single-loop web support structure for mounting the hammer slugs (or like reciprocating elements). In a general sense, such a composite structure may be thought of simply as an array of parallel fibers aligned primarily along a particular stress direction and comprising the bulk of the flexure support, being embedded in a minor portion of relatively resilient bonding material as a matrix. Such fibers may be either natural or man-made, may be of organic, inorganic or metallic material, and may comprise one continuous filament or discontinuous filaments, each filament comprising an individual fiber, a yarn, a yarn-bundle, etc. The matrix or binder material may, in general, be organic or inorganic (e.g. metallic) and can be made soft or hard, brittle or tough, conductive (elec. or thermal) or not; and resistant:

to weather, to heat, to chemical corrosion and to moisture, as the application demands. Of course, as aforesaid, the preferred structure is fiberglass filaments embedded in a thermosetting resin.

While the technical explanation behind the operation of such a two-phase slug support is not yet fully known, a great deal has been learned. As a general summary, the following characteristics may be noted. A fundamental assumption will be that the "strong" and "weak" (fibrous and matrix) materials act together as a unit (i.e., a monolithic cantilever beam) and that the two stretch, compress, twist, etc. under applied stress loads to a similar degree, so that both are distorted similarly. Thus, it has been found that to achieve this action, the following conditions must obtain:

(1) The fibers must all be essentially straight and (mostly) aligned in a common (stress) direction;

(2) The fibers must be arranged to be stressed to relatively the same degree;

(3) A good bond must exist between the matrix and the fibers and, although this bond need not be continuous, the bonding points must be close enough together to ensure that the two disparate materials can absorb strain unitarily. The key function of the bond is to transfer the load to the fibers, such as by preventing any appreciable slippage of the fibers, movement out of line with loading etc.; and

(4) The composite structure must be used only in the proportional stress/strain operating region (i.e., obey Hooke's law); that is, given an applied stress, the strain (elongation per unit length) of each material will be proportional to the stress it assumes.

Given the above conditions (and referring to stress/strain curves of FIGURE 2-C), we may appreciate the operation of the composite flexure in a tutorial manner by visualizing that it has a length L and is stretched by a weight W to elongate a distance dL , the fibers being lined up (elong. axis) exactly along the direction of the force (applied weight). The composite flexure must react to the weight force with an equal and opposite (stress) force, the major portion of this stress reaction being borne by the fibers. If both materials undergo equal unit deformation (strain), as they are assumed to do since they must act unitarily, the stiffer of the two will carry the greater stress (Hooke's Law) and this is what is intended, since the fibrous material is specified as stronger and comprising the major bulk. (Assumed that the composite flexure has relatively high glass density and that only the elastic range of (tensile) deformation is involved.) Energy-storage capacity may also be considered (area under stress/strain curve); as well as volume-efficiency (elastic energy capacity per unit volume—is inversely proportional to modulus). This composite flexure stores about five times the elastic energy (100–150 ft.-lb./in.³ is suggestive) of a like volume of spring steel and at about only 30% the mass (weight), giving the composite about 16 times the weight efficiency (high strength/weight). Of course, a lower modulus and/or a lower density will yield a higher weight efficiency. Of course, these tensile strength characteristics suggest analogous advantageous properties conclusions for, such flexures under shear strain as well.

Elasticity parameters

It is instructive for those skilled in the art to consider the elasticity (stress/strain), and related, characteristics of materials relative to their adaptability for purposes of the invention. It will be understood that, in general, elasticity (tensile) within the "proportional range" (Hooke's Law) is the ratio of stress S (i.e., load-resisting pressure within a material) to strain L (i.e., relative deformation, or elongation, of material under load). Of course, elasticity may also be defined in terms of bulk (volumetric, compression) stress; and of shear stress (i.e., rigidity under shear). Flexural elasticity (i.e., where stress tends to straighten a loaded, bending cantilever beam) combines both tensile and shear elasticities, of course. Thus, the

"moduli" (or elastic coefficients) of prime interest will be understood as the following:

The bulk modulus B (change in volume with pressure); the elongation modulus E (i.e., the tensile, or Young's modulus—relative elongation with pressure); and the shear modulus G (angular deflection with tangential pressure).

These elastic parameters are specified below for various flexure spring pivots including those formed according to the invention. Also referred to will be such related "mechanical-strength" parameters as:

Ultimate tensile strength S_t (rupture begins; after proportional limit exceeded); crosswise strength S_x (failure limit under a stress which is orthogonal to the flexing stress and/or the elongate stress); flexural strength S_f (elastic limit under flexural stress); flexural fatigue F_{af} (cycles to failure under specified flexure load—periodically applied, then entirely removed); impact resistance R_{im} (impact load causing failure) and maximum elasticity E_{max} (coefficient of maximum distortion; proportional to energy absorption capacity).

The composition two-phase pivot structure, in one preferred embodiment of the invention, takes the form of the aforementioned wound, fiberglass-reinforced, resin structure with high glass density (about 60% or more) and having exemplary "mechanical-strength" parameters which typically fall in the ranges indicated in Table I below. (SAE #1000 Spring Steel characteristics in double brackets for comparison.)

TABLE I

Impact resistance; R_{im} -----	6 ft.-lb./in. — "Izod" measure; notch, edgewise.
Interlaminar shear strength -----	4K p.s.i. (thousand lb./sq. in.).
Compressive strength (edge) S_c -----	90K p.s.i.
Tensile strength (S_t) -----	100–200K p.s.i. (along fiber length).
Flexural strength S_f -----	100–150K p.s.i. (10 at 90° stress angle) (vs. 180K p.s.i. for steel).
Flexural fatigue F_{af} -----	100M c.-fa. (million cycles to failure) at 30K p.s.i. 0.1 Mc.-fa. at 60K p.s.i.
Endurance limit -----	29K p.s.i. (vs. 33K p.s.i.).
Max. design stress -----	To 120K p.s.i.
Elastic (tensile) limit -----	—3% + elongation (circa .3–.4M p.s.i.).
Tensile modulus, E -----	5–6M p.s.i. (million lb./sq. in.).
Flexural modulus, F -----	4.5–5.5M p.s.i. (vs. 30M p.s.i.).

Assume about 70° F. test conditions above, using otherwise standard circulation technique.

It was surprising to find that a flexure pivot of these materials had such an unusually high volume-efficiency (energy absorption capacity per unit volume) e.g., on the order of about 12 ft.-lb./cu. in., or about $\frac{1}{10}$ its efficiency in tension (and about twice that of a comparable flat steel flexure). Such a structure will be about as "strong" as steel, but have a much lower elastic modulus, thus allowing greater deformation (within the "proportional region," of course). Such a composite flexure is also superior to steel in its high "strength/weight ratio," its corrosion resistance; in being "notch-insensitive" (no fatigue failure due to "notching") and the like, being surprisingly advantageous as a slug-supporting print-hammer pivot.

Matrix Material

As a potting matrix for the glass filaments in the embodiments, a number of common resins known in the art may serve. Epoxy potting materials are favored, but may be substituted for with any comparable relatively flexible material (i.e., relative to the stiffer filament material, having lower E , F etc.). This matrix material should

also be suitably adhesive (good bond to fibers), be moldable and have sufficient impact resistance, "crosswise strength" and the like. It should also resist water adsorption. Thus, one may use another thermo-setting resin such as a phenol, a polyester or the like and other elastomers compatible with the glass filaments and the application environment. Acrylics, Plexiglass and the like are less favored, however, because they are typically too brittle. Also, the maximum elasticity (e.g., maximum elongation at elastic limit, G_{lim}) of the matrix material should be very high (e.g., about 1 mil). For most purposes S_t , M_e , and F_{af} will be the most important parameters in filament selection; while for the matrix, maximum elasticity (i.e., a relative low M_e), S_x and R_{im} will be more critical. Thus, certain other plastic filament materials (e.g., nylon) may be substituted in certain cases, as well as suitable ceramics (e.g., asbestos) or metals (e.g., metal whisker) properly matched to the "mechanical-strength" parameters of the potting matrix and to the application environment. If it be assumed that a high, strength-carrying, bond exists between the glass fibers and the cured resin, then failure under stress is likely to occur via a shear straining of the resin phase no matter how the stress may be applied.

It will be seen (below) that the high strength fibrous material (e.g., the fiberglass strands) can be arranged in patterns to optimize resistance to the expected stress, whether it be in the circumferential, axial or other direction. For instance, as seen below, an array of fiberglass filaments may be potted in a plastic matrix to optimize their (already-high) impact-resistance, for instance, adapting them to be formed into hammer slugs (FIGURES 5, 6). It is estimated that the plastic by itself would have an impact resistance of less than one foot-pound per inch (f.p.i.); whereas when combined in this composite, the (fiberglass-resin) impact resistance becomes about 50 to 70 f.p.i. and; surprisingly, appears to resist impact even better than steel alloys heretofore used, although the cost of materials and fabrication are both much less. Such an arrangement has high shock-absorbing qualities, evidently stemming from the fact that the fibers have a tensile strength approximating that of steel, but a much lower modulus of (elongate) elasticity (Young's modulus or stretch-ability, permitting a greater stretch in the breaking region).

It is noted that the elastic (resin) material should tolerate a greater elongation (stretch) at break than the fiberglass (e.g., more than 5% appears desirable). Without this "stretch-differential" (to permit stress distribution between fibers), the real advantage of the composite structure is lost. For instance, the Young's modulus for Portland cement is about 10 million p.s.i. (M p.s.i.) and appears to be too close to (virtually identical with) that of glass, but only about one-third that of steel and about $5\times$ that of plaster of Paris. Thus, fiberglass could be advantageously dispersed in plaster of Paris, but not in cement; while steel in cement should work well. Thus, a composite support construction, according to the invention, will preferably comprise a major portion of a high cohesivity, relatively rigid (in direction of likely stress) material, like fiberglass strands. These strands are assumed to have a rupture resistance of the order of about 500M p.s.i. and a rigidity (shear modulus) coefficient of the order of 4M p.s.i.; with an elongate rigidity (Young's modulus) being about 10M p.s.i. These strands will be distributed in, and bonded firmly to, a matrix material which is relatively more elastic (deformable and "shearable"—also more "elongateable"), less rigid and comprising a minor portion of the composite mass. The matrix material may also have a much lower "cohesivity," e.g., comprise a resin having a shear-rigidity coefficient of the order of 0.2M p.s.i. and an elongate-rigidity of about 0.5M p.s.i. For these purposes it will be understood that this "shear-rigidity coefficient" RC (or "shape elasticity") is the ratio of shearing stress (p.s.i. parallel to a given

surface) to distortion strain (cf. the angle of shear or degree of distortion). This is usually related to the elongation coefficient EC (Young's modulus or "elongate-rigidity") or "non-stretch-ability factor" (in longitudinal p.s.i./percent elongation). Cohesivity TS will be understood as (longitudinal) resistance to rupture (p.s.i. required therefor).

Workers in the art will appreciate, upon considering the disclosure below, that great fabrication convenience and economies are derived, as well as other advantages, from the composite fiberglass/plastic construction of the invention. For instance, where bonding the slug and base to the slug-support has always been problematical, the composite amount of the invention may be firmly epoxy-bonded, or the like, with relatively no trouble. Moreover, economy and convenience are magnified when an array of such supports is fabricated from a single unit. For instance, a multi-coil, composite profile for about 120 such support-coils may be formed and bonded easily to a common base, being thus kept in prescribed fixed relation. Hammer slugs may then be bonded to each coil in the support array as detailed below. Convenience may be even further optimized by creating a fiberglass-plastic "board" from which a set of hammer slugs may be cut, to be bonded to the aforementioned fiberglass-plastic support array. Seldom has the art seen a development like this where improvements in structure, in fabrication, convenience, economy, reliability and operating response—are all jointly realized from the same design.

Objects

Thus, it is an object of the invention to provide such improved support assemblies, especially for print hammer slugs, or like reciprocating elements, providing the foregoing features and meeting the foregoing problems. A related object is to provide such assemblies from a composite construction using strong "bearing-material," like fiberglass filaments, in a weaker, more elastic "matrix material," such as a compatible resin or their equivalent. Another object is to provide such assemblies from such diverse-elasticity materials, i.e., a rigid, strong material (filaments) distributed in a matrix of relatively elastic (under prescribed stress) material. A further object is to provide such a composite structure in a coil or loop configuration, at least for fabrication purposes. Yet another object is to provide an improved mounting arrangement fabricated simply by coiling fiberglass strands in the form of a loop to be thereafter potted in a resin matrix.

Still another object is to provide a composite flexure support wherein a high strength, high modulus substance is disposed so as to have its greatest resistance to expected stress and wherein a relatively elastic material is adapted to have greater elasticity under this stress. Yet a further object is to provide such a fiberglass-plastic flexure wherein strands of fiberglass are aligned to best resist the expected stress. Still another object is to provide a fiberglass-plastic profile from which to form an array of hammer slugs and such a profile for forming an array of slug supporting flexures. Yet a further object is to provide such a fiberglass-plastic slug support which may be more readily bonded, such as with epoxy, to slugs and to a base. A still further object is to provide such a mounting arrangement wherein the base material and fiberglass support coil may be potted and bonded together in a plastic matrix. Still a further object is to provide such an arrangement wherein slugs may also be potted and bonded in the same operation.

The foregoing, and other related, features, objects and advantages are achieved according to one embodiment of the invention by coiling an elongate strand of fiberglass material endlessly about a prescribed coil profile, into a plurality of superposed layers, then potting this fiberglass coil in a plastic matrix having a relatively greater elasticity and adapted to encapsulate the separate coiled strands into an integral monolithic flexure-coil structure,

bonding or molding the coil with epoxy or the like to a base structure and to a hammer slug or a number of slugs, then finishing the hammer unit for incorporation into a high-speed printer.

Further objects, features and advantages may become apparent upon consideration of the following detailed description of certain embodiments thereof, especially when taken in conjunction with the accompanying drawings, wherein like reference numerals denote like parts:

FIGURE 1 is an upper isomeric view of a dual print hammer unit constructed according to prior art techniques and adapted for incorporation in a high-speed printer;

FIGURE 2A is a very schematic side elevation, in partial section, of a print hammer unit constructed according to the invention as an improvement over that in FIGURE 1;

FIGURE 2B is an end elevation of the unit in FIGURE 2A;

FIGURE 2C represents a somewhat idealized set of stress/strain curves;

FIGURE 2D is a section through the unit in FIGURE 2A along lines 2D—2D;

FIGURE 3 is an isometric "in-fabrication" elevation of a wound fiberglass coil of the type adapted, according to the invention, for fabricating support arrangements like those of FIGURE 2;

FIGURE 4 is an isometric schematic showing of an array of several fiberglass support coils similar to that in FIGURE 3, shown finished by plastic-encapsulation with a common base to comprise an integral multi-coil set;

FIGURE 5 is an isometric upper "in-fabrication" view of a multi-hammer profile, having been fabricated after the manner of the coil profile in FIGURE 4;

FIGURE 6 is an isometric upper view of a multi-hammer/multi-coil profile combining the features of the profiles in FIGURES 4 and 5.

FIGURE 7 is an isometric view of a profile embodiment like that in FIGURE 6, but finished and modified somewhat as to structure, materials and fabrication;

FIGURE 8 is a highly schematic frontal view of one in an integrated set (phantom and fragmented) of supports like those in FIGURES 1, 2 etc., somewhat modified in contemplated fabrication however; and

FIGURE 9 shows a support like that in FIGURE 8, somewhat modified in configuration however.

Referring now to FIGURES 1, 2A and 2B, it will be understood that a hammer unit HM is constructed, according to the invention to, generally, comprise a functional equivalent for prior art unit HU in FIGURE 1 (described above). Hammer unit HM includes a pair of coil-type hammer-supports (mounting) C, C_A, each adapted to support a metallic hammer slug S (or plurality thereof as described below) to be projected above a common base BV so as installed in a high-speed printer to be printing-reciprocated therein pivotally about BV (by means not shown) as is well understood in the art. The fabrication of coil supports, C, C_A preferably takes the indicated "loop" (or endless web) form and is fabricated as hereinafter described according to a feature of the invention. For convenience of fabrication, coils C, C_A may be made endless, as shown, and be potted into respective cavities in an associated slug and base. This is described below but may generally be understood as providing a base-potting (bs') and a slug-potting (bs, bs-s) serving to firmly bond a relatively large contact-area portion of the loop to the base and slug respectively—a difficult task using prior art constructions. A separate (prior) bond J, J' may also be used, as shown, or be dispensed with where not needed. As FIGURE 2D shows the slug-potting may advantageously surround both slug S, along a constricted segment thereof, and the adjacent segment of coil C, to bond both together—much better than conventional structures have. Hammer unit HM is thus a generally quadrilateral structure, as shown in FIGURE 2A, formed with opposed side segments CS and CS' both of

which join together a base BV and slug S. The side segments are flexible relative to the fairly solid base and slug.

According to a feature of the invention, coils C, etc. may be advantageously fabricated by winding fiberglass strands in a coil and potting them so in a resin matrix. This will be described as follows, with reference to FIGURE 3. Starting at a convenient point, PA, a long continuous strand of fiberglass material (such as Owens Corning Fiberglass G Filament Roving #801-4039-60 or a like wound bundle of glass, etc. fibers), Coil C will be wound in a continuous helical manner about a somewhat rectangular core or spool-form (not shown) of prescribed diameter to establish length L and height H (e.g., here, about $\frac{3}{4}$ " by 1"). The strands may be "pre-wetter" so as to bond intimately with plastic potting as seen below. This helical wrapping will continue in a first direction (away from PA) until (width) distance D is covered (e.g., here about $\frac{1}{10}$ in.), whereupon the winding direction reverses (cf. strand at point PB—in phantom from PA, establishing layer #1) and a second layer is begun at (PC, PC') to be reverse-wound as a superposed coil layer terminating adjacent the origin of the first at (PD). More such continuous, helical-wound superposed layers may be thus formed if desired. At length, a proper coil-thickness t (number of layers—here four, about 10 mils thick) is established, e.g., sufficient to give the finished (potted) coil a certain rigidity, as seen below (preferably 4 to 5 layers comprise coil embodiment C, one or two layers typically being too flexible). When completely wound, the coil C will comprise a somewhat rectangular structure (quadrilateral arrangement) having a pair of top and bottom (base) segments CB, CB' and a pair of left and right side segments CS', CS.

The "raw" coil so formed about its mandrel may then be coated with resin and cured in place (or alternatively, pre-coated for curing ease). It may thereafter be bonded to the slug S and base BV, as above indicated. However, preferably, this encapsulating and bonding is done in a single step, such as in a jig wherein the resin (e.g., epoxy) is poured to "pot" the sides CS, CS' and base CB of coil C, also forming bond-insets bs , bs' to firmly join the coil segments to the slug S and to base BV, respectively, as indicated in the finished product in FIGURE 2. For this purpose, the hammer and the base unit must, of course, be "bondable," i.e., include surfaces adapted to be suitably bonded to coil C, especially along an associated base. For instance, as described below, slug S may, itself, comprise a fiberglass-plastic structure and thus will inherently bond intimately with the fiberglass-plastic coil. Optionally, base BV may be simply formed by the epoxy potting step, per se, being polymerized in situ. The most promising resins (further below) were epoxides and polyesters (the latter are cheaper but more temperature-limited). The catalysts, curing agents, polymerizing conditions, etc. recommended by the manufacturers should be used. For some applications, it may be advisable to pre-load the finished, hardened composite coil (e.g., compressing it radically for a period at a slightly elevated temperature) to increase available spring energy, as known in the art. With this potting material cured, unit HM may then be conveniently finished as a single unit, such as by grinding its surfaces to the finished shape and dimensions.

One application for fiberglass-resin coil supports formed as aforementioned will be as print hammer (slug) flexure-supports C, C_A (aforescribed with reference to FIGURES 2A, 2B, 2C). Alternate embodiments will be contemplated by those skilled in the art, such as the similar 6-unit (6 slug) hammer module in FIGURE 7. Elements in FIGURE 7 have the same reference characters as the corresponding elements in FIGURE 2A, except that a prime (') is added in FIGURE 7. For example, the FIGURE 7 common base BV' is analogous to common base BV shown in FIGURE 2A. In certain cases

some or all of the base portions CB, CB' (either or both—FIGURE 3) may be cut-away to leave a pair of flat or C-shaped (or L-shaped) flexure supports which may be bonded between slug and base in their own (modified) manner, though greater bonding difficulties will typically arise in such a case. In any event, the resultant composite fiberglass/resin flexure-supports will exhibit certain desirable characteristics (as used in the slug-mount application, e.g., of FIGURE 2A). Characteristics typical of such operation are summarized for convenience in Table A below. However, it will be assumed that the fiberglass/resin supports CS, CS' (e.g. comprising support C in FIGURE 2A) have been formed into a pair of flat spring strips, rather than a continuous loop, being cut out, as aforementioned, such as from the sides of a loop coil like that (C') shown in FIGURE 3 or the like.

TABLE A (See FIGURE 2A)

20	Hammer Mount (HM) --	Operating freq.: 1000 c.p.m. Impact energy: 7.5-8K ergs.
	Slug (S) -----	Max. deflection: $\frac{1}{8}$ "; velocity: 133"/sec. Effect. Mass: 1.6-1.8 gm. Size: $1\frac{3}{8} \times \frac{1}{16} \times \frac{1}{16}$ " (min.) (std.). Hardness: RC 56-58.
25	Base (BV) -----	Size: $1\frac{1}{4} \times \frac{1}{4} \times \frac{3}{8}$ " (std.).
	Flexure (CS, CS') -----	Length (effective): 1"; width: 85 mils; thickness: 10 mils. Modulus of elasticity (of material): 5.5M p.s.i. (vs. 30M p.s.i. for equiv. spring steel). Moment of inertia: 4.6×10^{-9} in. ⁴ (vs. 0.8 for steel). Required force for $\frac{1}{8}$ " deflection: 45 gm. (about 30 gm. with steel). Hammer velocity: 133"/sec. (vs. 111"/sec. with steel)—settling time 8 m-sec. Bending stress: 28K p.s.i. (where modulus of section is 1.4×10^{-6} in. ³ and mass is 36.5 gm.).

Since each hammer slug S is supported by a pair of flexure strips CS, CS', their kinetic response in a flexure/slug unit may be compared to that of a pair of cantilevers guided by a bar at the free end (maximizing the moment at the free end). For small deflections, the path of the striking end may be assumed to be rectilinear with the effective length of the flexures remaining constant (though for large deflections this would not be valid). It will be understood that the deflection (x) of such a cantilever beam with guided ends is described by the relation: $x = WL^3/EM$, where: (W) is hammer weight, (L) is the flexure length, (E) is the elastic modulus and (M) is the moment of inertia of the section.

It will be assumed here that the load required for a unit deflection of this fiber-resin flexure is the same as with an equivalent steel flexure; hence, the elastic modulus/inertial moment product (EM) should be the same in both cases.

It was also interesting to find that the settling time was independent of flexure stiffness. That is, when a comparison was made between different hammer mounted on fiberglass-resin flexures of ten mils, of five mils, and of fifteen mils thickness, respectively, the settling time (measured with a rubber backstop) was found to be 8 milliseconds in all cases and was attributed (in part) to vibration of the armature actuator. Thus, it is not advantageous, in this case, to stiffen the flexure for reducing settling time—rather actuator vibration should be reduced. An effort was made to provide a hammer that would have the same mass and wear properties as a steel hammer

and yet be comprised, at least in part, of plastic so a plastic-plastic bond may be had with the flexure supports (C, FIGURE 2A) and yet the plastic-metal attachment with the slug must be very secure (where the slug is metal, as is typical). The provision of a plastic over-layer like *bs*, *bs'* (FIGURE 2A) for securing coil C to slug S and to base BV, respectively, can solve this problem, according to another feature of the invention. It is convenient, as well as preferable, to mold-in the over-layer pieces, such as when pouring base BV or thereafter. According to a sub-feature, the slug-joining over-layer *bs* surrounds both slug S (the concerned length thereof—preferably constricted therealong) and (that section of) coil C, pressing them together as indicated in FIGURES 2A and 2D.

Filament materials

It is critically important to specify the filament (fiber) material very carefully, primarily on the basis of strength, stiffness, cost and availability. Filament matrices come in a variety of forms such as yarn, "roving," cloth or sheeting of various configurations, the individual filaments being of large or small diameter, hollow or solid, etc. Generally, the filaments should be coated (with a sizing etc.) to protect against moisture, abrasion, etc. (prior to potting them) as well as to promote a good bond. Filament material selection will generally depend upon the design application, required properties, fabrication methods contemplated and cost of objectives. Workers are familiar with such exemplary materials as "E-glass," "S-glass," quartz and other, more specialized, glass filaments. For applications like those described (FIGURE 2, etc.) and (Table A), I have found that a very satisfactory filament material is a conventional fiberglass "roving" potted in epoxy.

As aforesaid, a preferred material is fiberglass which has a number of important advantages. It is noteworthy that a drawn-glass filament product (having a controlled, uniform diameter) is both different from, and superior to (for these purposes), bulk glass material. There are several dozen different formulations of non-crystalline glass fibers which have distinctive characteristics. Of course, significantly, they all offer a high "strength to weight ratio." Moreover, when heated, such fibers actually gain in strength (up to about 400 degrees F.; thereafter dropping back to about one-half strength about 700 degrees F.). When drawn into fine filaments (e.g., on the order of 0.1–0.01 mil in diameter), the strength of glass rises remarkably. For instance, where window glass has a tensile strength of about 6K p.s.i., that of laboratory-drawn filaments has been observed in excess of one million p.s.i. (M p.s.i.); for "commercial" filaments, this becomes about 500–700K p.s.i., dropping somewhat below this after processing-coating, bundling, weaving and so on. Various theories might be offered for this vast increase in strength with drawing (such as the "Griffith flow" theory, the "break-orientation" theory, the "molecular ordering" theory, etc.) but it is still largely an unknown. Thus, drawn glass filaments (fiberglass) when incorporated into a composite fiberglass support of the present embodiments should have a high "usable tensile strength" (in the neighborhood of 250–400K p.s.i.); whereas the plastic matrix of the support should be relatively weak (e.g., typically absorbing only about 4–6K p.s.i. before breaking). Combining these two materials is found to provide a composite flexure pivot that is surprisingly effective, having a tensile strength exceeding that of ordinary steel (i.e. about 75K p.s.i.; as opposed to the tensile strength of the finest steel: about 300K p.s.i.; and that of silica: about 650K p.s.i.).

It is also very important that the elastic modulus of the fibers be relatively high as compared to that of the matrix—that is, that there be sufficient disparity in their elastic behavior so that the matrix can deform elastically to the point where stress is thrown mainly to the fibrous network. (The high usable tensile strength of the fibers

also facilitates this stress-transfer.) Thus, for instance, the glass filaments will have an elastic modulus of about 10M p.s.i. (and elastic limit about 3–4% elongation at .3–.4M p.s.i.) compared to a modulus of about 0.5 to 1M p.s.i. for a typical thermo-setting resin. Indeed, by using the latest high silica glasses (with a modulus as high as about 16M p.s.i. and a tensile strength about 650K p.s.i.), one should be able to build fiberglass-resin composite having a tensile strength comparable with the finest steels (i.e., about a few hundred K p.s.i.).

Of course, the load distribution between fibers and matrix in a composite will depend upon how much more rigid the fiber is and upon the volume-percentage of fiber present. The "tensile strength-cross section product" of the composite will be the sum of those of the two constituents. Thus, a high proportion fiber (reinforcement) will usually be desirable, though not so high as to impede the infiltration (during fabrication) of the matrix material. Note that glass fibers are typically about ten times as rigid as the typical plastic they reinforce and hence, it is not necessary to provide a very high percentage of glass to throw most of the load (stress) to the fibers. Composites whose constituents have less of a spread in their elastic moduli, however, will require a higher fiber concentration to achieve a similar fiber loading. It will be apparent that there are other determinative fiber characteristics, such as fiber-orientation, ply orientation (when a laminate is used), flexural properties and the like. These are noted below in discussing the characteristics of the overall composite fiberglass resin pivot embodiment.

It will be apparent that although the aforementioned fiberglass material is preferred, there are other fibrous materials available. For example, in certain environments, one may use fibers of: reinforced minerals, asbestos, nylon, ceramic, metallic strands (e.g. glass wool) etc., each in an appropriate matrix. Metallic "whiskers" will be suitable for some applications, observing certain precautions, as follows. First, it should be understood that the strength of such whiskers will be governed by the number of dislocations in the crystalline structure and flaws on the surface. With increasing whisker diameter, the number of lattice dislocations and surface defects increases so that whiskers with large diameters frequently exhibit low strength and break with small elongation (below about one percent). However, fine-diameter whiskers have superior strength and can sustain elongation up to about three percent. Representative whisker materials will be: alumina (sapphire), beryllium, silicon carbide (SiC), silicon nitride, graphite and boron-carbide (B₄C). By way of example, graphite will be observed to be the stronger, mechanically, in this group, having the following properties: median tensile strength 3M p.s.i.; Young's (stretch) modulus 100M p.s.i.; break elongation about 2% and the highest thermal stability (i.e., to about 3000° C.). (By comparison, the silicon nitride will have about the lowest tensile strength, lowest stretch modulus and lowest thermal stability (heat resistance); while the borocarbide will rupture at the lowest percent-elongation.) Interestingly, the silicon carbide whiskers often exhibit a nodular surface growth and will generally be weaker, though superior for adhesion in the matrix (whereas alumina is usually free of such nodes). Of course, the filaments should bond well to the matrix material and not react with it, have a like thermal expansivity, etc.

Matrix characteristics

There are several important characteristics of the matrix which must be borne in mind for practical application of the invention. It has been stated that the relationship between the stiffness and the strength characteristics of the fiber and the matrix material is a key factor in producing a successful composite material (for the subject flexure-pivot applications). The matrix will, as stated, be selected to be more resilient (less stiff) than the fibers;

that is, will have a lower elastic modulus so that, under load, it will give elastically and transfer the load primarily to the fibers. Thus, the fibers will be highly stressed, where the matrix will not. As aforesaid, it is assumed that the fibers are selected to be strong enough to assume this high stress without breaking—there being sufficient fibers for this and the fibers being disposed to distribute this load relatively uniformly.

Many plastics are suitable matrix materials and various metals and ceramics may also be used, particularly in high-temperature environments where organic polymers will not serve. The principal plastics of interest will be polyesters, epoxies, silicones and phenolics. For rugged electrical applications, the melamine formaldehyde resins are also useful. Acrylics will be useful in some applications, as will some of the new polyimides especially at high temperatures.

Polymers offer the widest range of physical properties and processing conditions of any of the resins. They can be cured at room temperature and atmospheric pressure, necessitating a minimum of equipment. Polymers can also be cured under pressure and at temperatures to 300° F. Properties can, of course, be modified by adding monomers, flexibilizers, promoters and fillers to the basic formulation. Hardness, or catalysts are generally required and will affect curing characteristics (e.g., viscosity, gel time, pot life) as well as the heat resistance, strength and elongation properties etc. of the cured resin. Styrene monomers may be used as a solvent for the polymers to control viscosity and to serve as a cross link in polymerization. Chlorinated acid or other chemical compounds may be added to increase fire resistance. Glycol additives may be used to improve chemical resistance and "weather-resistance."

Silicones will be useful where a premium is placed on stability, mechanical and electrical, under a wide range of "severe" environmental conditions, such as extremes of: temperature, of radiation (IR or UV exposure) and of caustic chemicals. Silicones are also very resistant to arcing and to oxidation (and general "weathering"); as well as having low moisture absorption. However, their high cost, relatively low mechanical strength at room temperature and their difficulties in handling and in bonding (e.g., to glass) will limit their application, of course.

Epoxy resins are prime candidates for matrix materials. These low molecular weight resins may, of course, be cross-linked with an amino acid, or other resin linking agent, which, being chemically incorporated in the resultant compound, will affect its properties. Epoxies are known to have excellent shelf life (until the hardener is added) and formulations with long pot life are available, though variations are not so wide as with the polyesters. Epoxies are, of course, outstanding for their adhesive properties (low shrinkage with high mechanical and bond strength), good wetting characteristics, low moisture absorption, good chemical stability and easy handling—making them especially useful in laminating applications, except where low cost is paramount or high temperatures are involved. A polyester or phenolic will be cheaper, though not as high grade in performance.

Polyester resins are a "workhorse" material due to their low cost, ease of handling and ability to cure at low (e.g., atmospheric pressures). Their strength, dimensional stability and electrical properties are good; though very high temperatures will limit their effectiveness.

On the other hand, phenolics are most attractive where low cost is paramount and one can tolerate their average strength characteristics and their processing problems (pressurized cure, water condensation during polymerization and difficult bonding to glass). However, their bond strengths, toughness and electrical properties are definitely inferior to epoxies.

Of course, when resins are employed certain shrinkage-induced stresses should be contemplated. That is, stresses should be expected at the glass fiber/resin interface, as

well as within the matrix material itself. Such stresses will result from contraction (i.e., difference in Poisson's ratio dW/dL under tensile stress) as well as from shrinkage. More particularly, when a glass filament is surrounded by resin, a tensile stress parallel to the fiber will cause the resin to contract more than the glass and thereby create a compressive radial stress. Also, other regions may be subjected to similar compressive radial loading. Further, shrinkage will be a factor since thermo-setting resins, be they polyesters, epoxies, phenolics, melamines or silicones, do all shrink; that is, during the curing and cooling of the resin, they increase in density (increased mass per unit volume) and, thus, must shrink. Some shrinkage would appear beneficial since it causes the resin envelope which "wets" the glass fiber to grip it more tightly. Shrinkage is natural to expect when a liquid polymerizing resin solidifies. Some metals also appear to be promising matrix materials (for the proper, matched filaments) such as iron, nickel, cobalt, titanium, zirconium, beryllium and chromium, etc. Such metal "binders" should keep a good bond even under high temperatures and should be capable of plastic flow so as to distribute stress loading.

Of course, it will be understood that, once the desired materials for filament and matrix are selected, as above, provision must be made to assure a fine bond between the two, such as by providing a complex organic-inorganic coupling-agent coating on fiberglass filaments that the organic portion may react with the resin matrix and the inorganic portion with the glass. Such a coating serves to protect the glass fiber also.

Fiber arrangement

Reinforced plastics that are designed for fatigue resistance differ in composition and structure from most other fiber-reinforced-plastics. They can best be described as "non-woven laminates" produced from cured sheets or uncured sheets or, preferably, from helical winding etc. according to the method of the invention. Their fatigue resistance properties depend largely upon fibre orientation and upon the type and composition of the matrix-resin used.

Non-woven, continuous glass fibers perform best when molded, fiber-reinforced, laminates are prescribed for fatigue resistant applications because they provide higher strength than either woven, continuous fibers or short, randomly distributed, fibers; and also because the fibers can readily be oriented to give optimum strength and stiffness in the needed direction. Glass fibers, in general, have a high energy-storing capacity and yet have a relatively low density and a low modulus compared with metals (high strength/weight ratio). Moreover, the relatively low, controllable modulus of the glass fiber-resin composite allows it to withstand deflection without producing excessive stresses.

Of the various thermo-setting resins commonly used in glass fiber reinforced laminates, the best fatigue properties are obtained with the epoxy resins rather than phenolic, polyester or silicone laminates. This superiority is attributed to the inherent toughness and durability of epoxy resins, which, additionally, have high mechanical strength, low shrinkage during cure, and form an excellent bond with the glass fibers.

The fatigue properties of fiberglass-resin laminate varies with resin content. While there is a surprisingly small change in fatigue strength with various resins proportions at low fatigue levels, a resin content outside the 20-40% range gives less than optimum fatigue strength. Also, it is risky to use non-woven, reinforced plastic parts for long-term applications where resin content has been lowered about 20%, since, below this point, tensile strength is usually degraded.

The fatigue properties of an oriented non-woven fiberglass laminate also change with ply orientation, as well as depending upon resin and filament materials. For exam-

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ple, aligning a unidirectional laminate along the stress (tensile) direction ("zero degree orientation"), surprisingly, results in a performance which is well below optimum. That is, splitting occurs in the fiber direction due to the relatively low fiber strength perpendicular to the direction of reinforcement. A few degrees "bias orientation" (i.e. misalignment from this stress direction—on the order of about 5°) overcomes this "zero degree" problem and still retains most of the high axial strength of the "zero degree" laminate. Another way of overcoming this splitting problem is to make the laminate with most of the plies at "zero degree," but have a few plies cross-oriented at 90 degrees.

The fiber orientation of a non-woven continuous filament laminate results in considerable improvement in fatigue strength as compared to a woven glass (cloth) laminate. A cross-ply non-woven laminate with 50% zero degree and 50% 90° plies gives much better fatigue strength than unidirectional (zero-degree) fibers, even though both laminates have the same reinforcement pattern. Highly-oriented, non-woven, continuous-filament laminates have an axial fatigue strength level of 30,000 to 40,000 p.s.i. This compares favorably with metals like aluminum and is about three times the fatigue strength of woven continuous filament laminates (e.g., made with "style 181" glass fabric); and about ten times the fatigue strength of typical unoriented glass mat laminates.

Similarly, the tensile strength properties of filamentary composites according to the invention are high (surpassing metals of like weight) and are rather strongly directional. For example, certain fiberglass-epoxy (unidirectional) laminates can vary from several hundred K p.s.i. under axial loading to a fraction of this as the loading angle increases a few degrees. The compressive strength properties will be similarly affected.

Flexural fatigue, energy storage

In addition to the influence of materials and design on fatigue strength, the type fatiguing action also affects the behavior of fiber-reinforced plastic flexure pivots. Flexural bending fatigue data on the loading of flat laminates (having the above cross-ply orientation preferably at about 45° with respect to the loading direction) shows that these have a somewhat higher fatigue strength in flexure than in axial fatigue (assuming alternating tension and compression loading). Pure (un-reinforced) unidirectional materials also show higher fatigue strength in bending than in alternate tension/compression axial loading.

Comparing fatigue and flexural properties of several reinforced plastics, metal and wood materials for structural flat springs, the following has been found. (Fatigue data based on flat unnotched specimens tested at room temperature and at zero mean stress with an alternating reverse stress amplitude. Fatigue strength is determined from fatigue life tests and is the maximum stress at which the material will endure 10^7 cycles of deformation.) The flexural fatigue strength of an oriented non-woven laminate may be expected to be about twice the fatigue strength of a woven laminate and three times the strength of a random-fiber molding compound, being comparable to SAE 1060 spring steel on a unit weight basis.

The permissible strain of a spring is a measure of materials deflection or available amplitude of spring action. The relatively high "ultimate" strength and "bending fatigue" strength of an oriented non-woven glass fiber laminate, coupled with its relatively low modulus, provides a superior spring action; e.g. many times better than SAE 1060 spring steel. A very important spring property is its energy-storing capacity when the material is deformed from zero stress up to its fatigue limit. (The energy stored in a stressed material is equal to the area under the stress/strain curve.) The relatively

low modulus of oriented non-woven reinforced plastics (10%–30% that of steel), coupled with its high ultimate strength, provides it with a much greater energy-storing capacity than SAE 1069 spring steel.

Damping is the process whereby a (spring) material absorbs energy (transforming it into heat). The damping capacity of a material is believed to have a significant relation to its fatigue properties. Damping energy is a material-property that does not depend upon previous stress history; specific damping energy is a direct measure of the mechanical energy (converted primarily into heat) lost per unit volume material for each cycle of loading. A high specific damping energy is associated with a lower amplitude of resonant vibration and a faster vibration decay. The specific damping energy of a reinforced plastic may be superior to several metals generally.

In summary, it will be apparent to those skilled in the art that two-phase composite flexure supports, such as the fiberglass-resin composites of the invention, are quite advantageous. For instance, as opposed to unreinforced (single phase) materials, fiber reinforcement enhances mechanical strength parameters such as giving:

Increased tensile strength; increased resistance to impact; vibration and shock; increased stiffness; controlled dimensional stability; reduced creep and improved frictional properties and wear resistance. It also reduces thermal distortion, improves electrical conductivity (and special nuclear properties); it facilitates high-speed production methods (without sacrificing performance) and achieves special effects—all in combination with providing a material that has much higher strength and impact resistance than unreinforced material. Glassfiber/plastic supports can be designed for strengths above those of alloy steels. Composites with high-modulus filaments (e.g., glass, boron, alumina) in a weaker matrix (like a resin) can exceed structural metals (single phase materials) in efficiency, strength and cost considerations; can reduce creep and raise heat distortion temperature and the like (even with low reinforcement percentages).

Summarizing the more salient design features for the preferred fiberglass-resin pivot flexure, one should select filament materials for good load-bearing properties, fatigue strength and the like according to the application requirements; should select a relatively more "ductile" matrix to simply transfer stress without failing (i.e. with lower modulus, good tensile strength, etc.); and should provide a very good filament-matrix bond (e.g., with coupling agent on filaments). Most of the filaments should be aligned along the contemplated loading direction; with a minor portion serving as a cross-ply (lamination for fatigue strength, etc.) and of a material selected to provide an adequate load-bearing capacity at a given relative volumetric proportion (relative to the matrix volume). Optimally, a minor portion of filaments are oriented transverse this direction for transverse strength (resistance to matrix failure etc.). Also, joints will be eliminated where possible (integral construction).

Workers in the art will recognize many advantages of pivot supports formed like those aforementioned. Some such advantages are: controlled anisotropy of properties (e.g., composite "tailored" to be stiff in one direction, resilient in another), "field transparency" (i.e., unaffected by electromagnetic fields) corrosion-resistance (chemically inert, even at somewhat elevated temperatures) great resistance to crack propagation, high ratio of strength- (and stiffness)-to-weight (high yield strength, high elastic modulus/density), and the like. However, certain limitations should be kept in mind, such as those aforementioned, including some obvious resin-induced limitations (when resin matrix used) such as poor resistance to: abrasion, to mechanical and thermal cyclic stress and to certain intense radiation (e.g., UV). The resin may also be degraded by water absorption or by very high temperatures (may burn resin or soften glass, etc.). Also the anisotropic strength properties will be a dis-

advantage under complex loading. Of course, it is known that, in general, fiberglass-resin (or other "two-phase") materials may be used for fabricating composite structures such as springs etc. (e.g., consult 1959 issues of "Product Engineering" such as Aug. 17, 1959 or Nov. 9; however, the foregoing features of novelty will enable workers to call forth new and useful improvements over such known structures, especially for "print-hammer support" applications and the like.

Variations

Workers in the art can visualize other pivotal support structures, analogous to that of FIGURE 2A etc. wherein the aforescribed two-phase (e.g. fiberglass/resin) construction is aptly employed. One such structure comprises forming a coil (like C, FIGURE 3) of metallic filaments (e.g., of steel or like, "high strength" conductive metal—preferably resin-coated) to be molded and potted in epoxy or like adherent non-metallic and relatively "weak," elastic matrix. It will be appreciated that such a pivot-coil will not only form a support structure for a reciprocating element (print slug) but can also function to electro-magnetically actuate (drive) it. That is, if this coil is disposed in the field between a pair of permanent magnets and connected to a source of potential, a current pulse can be applied through the coil to cause it to be thrust, driving the slug print-wise. To optimally drive such a solenoid-support for a print-hammer, a first actuation pulse may drive the unit in "Reverse," away from the print-paper, thereby storing (spring) energy; followed by a (synchronized) opposite-polarity pulse to drive it "Forward," (in the print-impact direction), and thus amplify the printing force, ("solenoid-cocking" action).

Whatever filamentary material is used, various equivalent support configurations may also be used in appropriate cases. For instance, while the filaments should be laid generally parallel (along the coil-length L) and fairly close together, it will not always be necessary to wind them helically or continuously, though this a great fabricating convenience. Further, though coil C' preferably comprises an endless coil (or belt-like structure), in certain cases, it may be made to be discontinuous, e.g., being formed by cutting out the center portions of bases CB, CB' in FIGURE 3 to leave a pair of "C-shaped" supports (sides CS, CS' plus curved end-extensions) to be bonded to the hammer and base in the foregoing manner. Similarly, it may be appropriate in some cases to wind the filament-strand discontinuously, or so it comprises several parallel sections, each comprising a single multi-turn filament, or the like. In some cases, prefabricated sheets (e.g., of fiberglass in resin, with oriented fibers in a partially cured epoxy matrix) may be used.

It will be appreciated that coil support C, or its equivalent, may be fabricated so as to function (when used to support a print-slug S) in a manner roughly similar to prior art flexure strips, such as strips *f* in FIGURE 1. That is, leg segments CS, CS' (FIGURE 2A) will be substantially rigid along their "length" (between slug and base) since coil C is intended to be somewhat rigidified along the filamentary length by the potting. Similarly, leg portions CS, CS' will have a prescribed actuation-resilience in the "actuate-direction" (striking direction H, arrows FIGURES 1, 2A) as to provide a prescribed rebound action (once such control parameters as hammer mass, excursion distance, striking force, etc. are prescribed). However, support coil C appears to have some unique operating characteristics as well. For instance, it appears to have a significantly longer reliable operating life compared to its predecessors, having been fabricated and test-operated in excess of twenty million print cycles with essentially 100% reliability, i.e., with no failure during fabrication and no failure, or even apparent deterioration, during extended life-test. It is believed likely that the aforementioned composite construction is largely responsible for this. Another contributing factor may be

the loop configuration and the manner of bonding it to the base and slug. That is, it is evident that, since coil C may be epoxy-bonded to both slug S and base BV, no sharp stress-discontinuities will likely develop adjacent its juncture with these elements. Such stress-discontinuities are suspected of causing failure in prior art supports. For instance, flexure supports *f* in FIGURE 1 appear subject to such stress since they too frequently rupture adjacent their point of emergence from their terminal (hammer or base) bonds. Further, since the bond area (coil-slug and coil-base) is greatly enlarged, extending for a rather substantial distance, there is little chance of failure due to bond separation, as sometimes happens in the prior art with catastrophic consequences.

According to another feature of the invention, the coil-fabrication technique (e.g., as described in connection with FIGURE 3) may be advantageously extended to fabricate a set of (plural) slug-mounting coils, rather than the single coil aforescribed. For instance, the fabrication indicated in FIGURE 3 might be modified so that coil depth D extends sufficient to span the installed length of a set of twelve print-hammers, epoxy-coating the multi-support coil formed and potting it as an integral unit with a common (e.g., epoxy-molded) base. Such a multi-coil-array is indicated in FIGURE 4 where the coil length has been extended (DD) to span four print-hammer positions. This "extended" coil (multi-coil "profile" CP) will be understood as having been epoxy-coated, as aforescribed, and molded with a common base B'. Individual coils C-1 through C-4 are also indicated as having been cut-out (inter-slug separation spaces cut-out) so as to occupy, each, the relative (pre-aligned) position of a respective slug in the set (this construction making it very easy to cut out such intermediate sections). In this respect, it should be noted that such a composite, fiberglass-plastic coil is not only easy to cut, but also tolerates cutting with no risk of degraded characteristics, i.e., the remaining coil structure maintains its integrity, even under stress, and is not subject to the aforementioned "notch-sensitivity" of homogeneous structures, such as spring steel flexure strips *f* (FIGURE 1). It will be recalled that the composite structure can function so that when individual filaments are broken, the others assume the load as transmitted by the elastic (resin) matrix. Of course, it will be recognized that with such a composite coil structure, using a plastic or other "soft" matrix, care must be taken to minimize needless abrasion, cutting, etc. of the remaining coil structure, since while it tolerates cutting better than homogeneous metals, it does not resist it as well.

According to another feature of the invention, the aforescribed techniques for fabricating composite filament/matrix structures may be modified for fabricating impact elements (e.g., hammer slugs) and especially sets of them. FIGURE 5 indicates a fiberglass/resin embodiment of this feature, while FIGURE 6 indicates how a slug-profile per FIGURE 5 may be fabricated in a multi-unit mode together with a multi-coil support module (much like that of FIGURE 4). That is, a set of hammer units (analogous to HU, HM above) may be sliced from a common "multi-hammer profile," MHU, comprising slug profile SB' and coil-profile CP'. The multi-slug profile "board" SB indicated in FIGURE 5 will be understood as fabricated by laying down a matrix of high strength, rigid filaments of fiberglass or the like to be relatively parallel with the direction of expected impact-stress, i.e. the "thrust direction" (arrow *i*). These filaments are then potted in a relatively more elastic (plastic) matrix, as with coils C, C' etc. aforescribed. Such a board SB may then be machined (e.g., to shape its forward, or print-head, portion and its tail, or driven, portion) conveniently as an entirety. Individual hammers S'-1 etc. may then be cut from board SB; or, alternatively, the entire board may be bonded (as indicated for SB' in FIGURE 6) to an associated multi-coil-base structure

(C'', B'' comprising coil profile CP'), thereafter cutting out the overall profile MHU to form individual hammer-coil units in a (matched) set. Workers in the art will appreciate that as opposed to individual hammer-forming, this technique is not only more efficient, but gives greater assurance of "matching" a set of hammers regarding their materials, surfacing (ground and sliced as a set) as well as making their relative positions automatically registered (simply via the aligned cutting process—with no fussy assembly-jigging, etc. as presently required).

Thus, the two-phase filamentary construction can be advantageously adapted for constructing print-hammer slugs alone or in a multi-hammer profile; providing improved manufacturing efficiency and, apparently, improved fatigue life. However, it may be advantageous to provide metal (insert) faces at one or both striking ends of board SB, and like adaptations as will occur to those skilled in the art.

Workers in the art will appreciate such "modular" (or multi-unit profile) fabrication because of the attendant improvements in operation and in reliability, improved ease and economy of fabrication, etc. Such fabrication techniques, for slug profiles, coil profiles and the like can generate substantial savings, as opposed to fabricating individual units (such as HU in FIGURE 1) and moreover result in a more efficient multi-hammer unit, as opposed to aligning and affixing units in a printer individually. Such fabrication in pre-oriented hammer modules according to the invention is also vastly superior for easily securing a precise alignment of hammers (relative one another and relative to the printer)—something of the highest importance in printer fabrication and maintenance. Workers know that the nominal spacing between hammers is customarily a mere 15 mils (.015 inch). It will be appreciated that hammers can thus easily brush against one another during printing, whereupon, the print-timing and energy level is radically upset, such an occurrence being not uncommon today. The invention should greatly reduce this. Also, this convenience and the evident cost-reduction provided by the invention will make it more feasible to provide a plurality of different-spacing hammer sets (for different column-spacing) and "change-format" easily, the location of the separation slots cut into a module MHU being all that is necessary to fabricate these. Moreover, such hammer sets will also be quite convenient to install.

It will be apparent to those skilled in the art that other advantages also accrue from this two-phase (multi-hammer) modular construction. The advantages and economies in establishing and maintaining accurate hammer placement have been mentioned; however, a related advantage is "replacement convenience." That is, high speed printer assemblies associated with a data processing system customarily involve a very high hourly (rental) expense, so that failure of only one or two of their hammer units, disabling the printer (and associated equipment) is very expensive, virtually as harmful and expensive as failure of all units, the value of parts being minor relative to the cost of system "downtime." For instance, a single high-speed printer may typically incorporate more than 60 "dual-hammer" mounting assemblies and the downtime (as well as labor expense, dismantling, etc.) involved in replacing one broken hammer unit will be virtually the same as that for replacing several units or even all units. Therefore, it becomes critically important in the design of such hammer units, to guarantee a virtual 100% reliability over a prescribed life, e.g., so that a serviceman may periodically replace the entire hammer array (after a prescribed "minimum life") and thus likely prevent any hammer failures at all. The composite fiberglass/resin hammer construction of the invention is seen as being uniquely apt for providing this reliability and convenience of replacement, especially when implemented according to the foregoing modular fabrication techniques.

FIGURE 9 shows, very schematically, a pivotal support element 10-S functionally analogous to supports *f* in FIGURE 1 or CS, CS' in FIGURE 2A, etc. and intended to support an element (e.g., a slug S) in pivotable relation with a relatively fixed base member 10-B (like BV). Support 10-S is affixed to base 10-B (e.g., stamped-out integral therewith) and, according to this feature, is "tapered" laterally, having a pair of sides SD, SD' symmetrically converging from base segment E₀ to shorter tip-segment E_t at like angles of convergence A-1 (e.g., a few degrees less than 90°). Workers in the art will recognize that such tapered supports are very stable laterally, and thus, quite advantageous for mounting print-slugs (e.g., especially in a Chain-Printer, where lateral stress can be most severe). A schematically-indicated multi-support variant is indicated in FIGURE 8 where a number (here, two) of such tapered supports 9-C, 9-C' may be projected from a common base element 9-B (e.g., be all stamped out in common).

According to the foregoing, the objects of the invention will be seen as attached in the several embodiments and modifications thereof. Since certain of the described features may be selected and modified, in implementing the above-indicated methods and structural designs of the invention without departing from the scope of the invention as claimed; and since, in some cases, certain features of the invention may be used to advantage without a corresponding use of other features, it will be understood that the foregoing descriptive matter and illustrated embodiments shall not be interpreted in a limiting sense, but only as propaedeutic and illustrative of the best forms of the invention known, as called for by the patent statutes.

It will be readily apparent to those skilled in the art that the principles of the present invention are otherwise applicable. For instance, the described composite flexure pivot construction (and/or fabrication techniques) may also be used for mounting (flexure-pivoting) reciprocating impact elements other than print-hammers, such as actuators (e.g., for hammer slugs; for solenoid armature, etc.) driving cam elements, punches (e.g., for cards, tape) interposers, document-feed means (e.g., pinch roll, picker, etc.) or flexure-pivoted couplings (e.g., a punch-bail to an eccentric shaft), or the like.

Having now described the invention, what is claimed as new and for which it is described to secure Letters Patent is:

1. Impact-producing apparatus of a generally quadrilateral arrangement formed with one pair of first and second opposed, relatively rigid members and another pair of third and fourth opposed, relatively flexible members secured at their end portions to said first and second members, and wherein said first and second members form respectively a base member and an impacting member movable relative to said base member, said apparatus being characterized by the improvement wherein each of said third and fourth members comprises

plural filaments having a relatively high elastic modulus and extending principally along the lengths of said third and fourth members over the full span of said third and fourth members between said first and second members, and

binding material having a relatively low elastic modulus and adhered to said filaments.

2. Apparatus as defined in claim 1 wherein said binder material is selected from the group consisting of polyesters, epoxies, silicone resins and phenolics, and wherein said filaments are fiberglass.

3. Apparatus as defined in claim 1 wherein said fibers and binder form a continuous closed loop that forms said third and fourth members, and has two opposed segments intermediate said third and fourth members, one segment forming at least part of said base member and the other segment forming at least part of said impacting member.

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4. Apparatus as defined in claim 1 wherein each of said third and fourth members is C-shaped, each such C-shaped member having a central portion intermediate two end portions, one end portion being secured to said impacting member and the other end portion being secured to said base member. 5

5. Impact producing apparatus comprising a pair of first and second, opposed, relatively rigid members and a third flexible quadrilateral member having upper, lower, left and right portions, said lower and upper portions being solidly affixed to said first and second members, respectively, and wherein said first and second members are movable relative to each other, and wherein said third member consists essentially of plural fiberglass filaments having a relatively high elastic modulus and extending principally along the length of said third member and resin binding material having a relatively low elastic modulus adhered to said filaments. 10 15

6. In the manufacture of a print-hammer mount for carrying a reciprocating print-slug into impacting movement relative to a font-carrying member, said mount having a slug-receiving member reciprocatingly moveable relative to a base member spaced from said slug-receiving member, the steps of 20

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arranging plural flexible filaments substantially parallel to each other in a closely-packed elongated bundle structure,

binding said filaments together with a flexible binding material impregnated between said filaments, and securely interconnecting said font-carrying and base members by means of said bundle structure so that flexure of said bundle structure allows said slug-receiving member to reciprocate relative to said base member.

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