United States Patent [19]

Frohrib

[11] **3,742,800**

[45] **July 3, 1973**

[54] **CONSTANT FLEXURE STRESS ENERGY STORING BEAM**

[75] Inventor: **Darrell A. Frohrib**, St. Paul, Minn.

[73] Assignee: **The Regents of the University of Minnesota**, Minneapolis, Minn.

[22] Filed: **Jan. 10, 1972**

[21] Appl. No.: **216,740**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 53,538, July 9, 1970, abandoned.

[52] **U.S. Cl.**..... **83/587**, 83/575, 83/597, 173/100, 234/108, 234/109, 310/27

[51] **Int. Cl.**..... **B26d 5/06**, B26d 5/08, B26f 1/02

[58] **Field of Search**..... 83/587, 586, 575, 83/589, 597; 234/108, 109, 115; 173/100; 310/15, 25, 27; 267/158, 160

[56] **References Cited**

UNITED STATES PATENTS

2,599,036	6/1952	Efromson et al.	310/27
2,838,700	6/1958	Bligard	310/27
2,999,632	9/1961	Tailleur	234/109
3,055,250	9/1962	Hubbard	83/587 X
3,123,290	3/1964	Rabinow et al.	234/115
3,453,919	7/1969	Ehrat et al.	83/589

Primary Examiner—Frank T. Yost

Attorney—Robert W. Gutenkauf et al.

[57] **ABSTRACT**

A flexural energy storing beam for use with punching and printing hammers in computers and high speed data processors, said beam having a contour optimized according to the energy input whereby in the bending of the beam the maximum principal stress is constant at every cross section of the beam.

6 Claims, 5 Drawing Figures

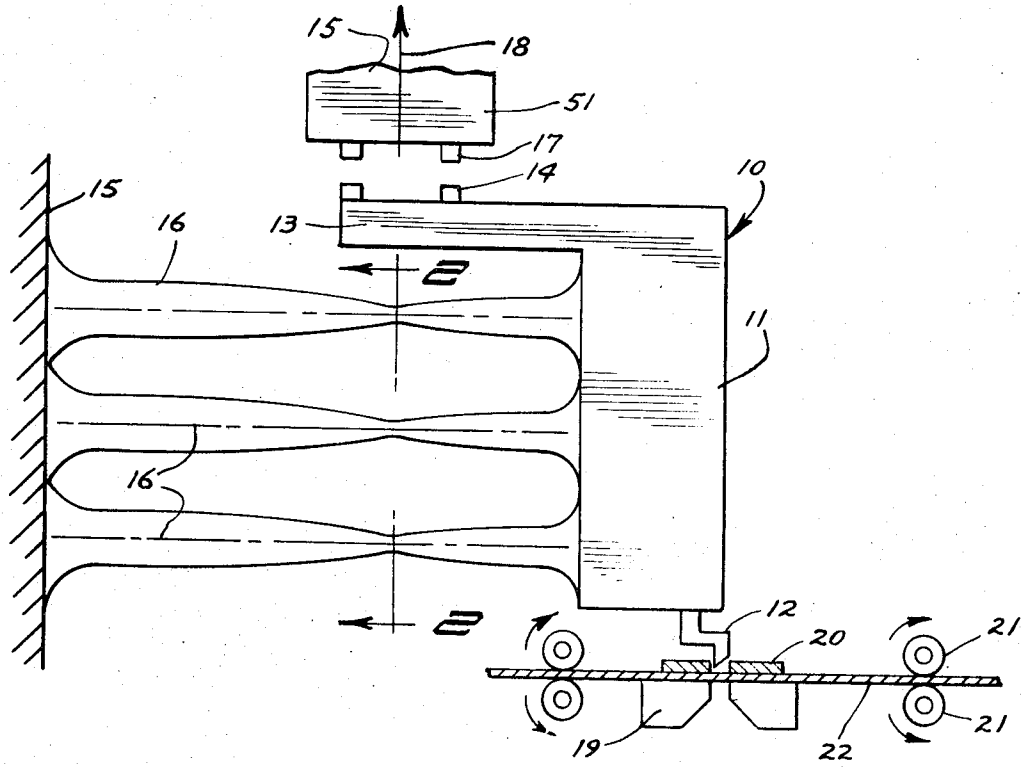
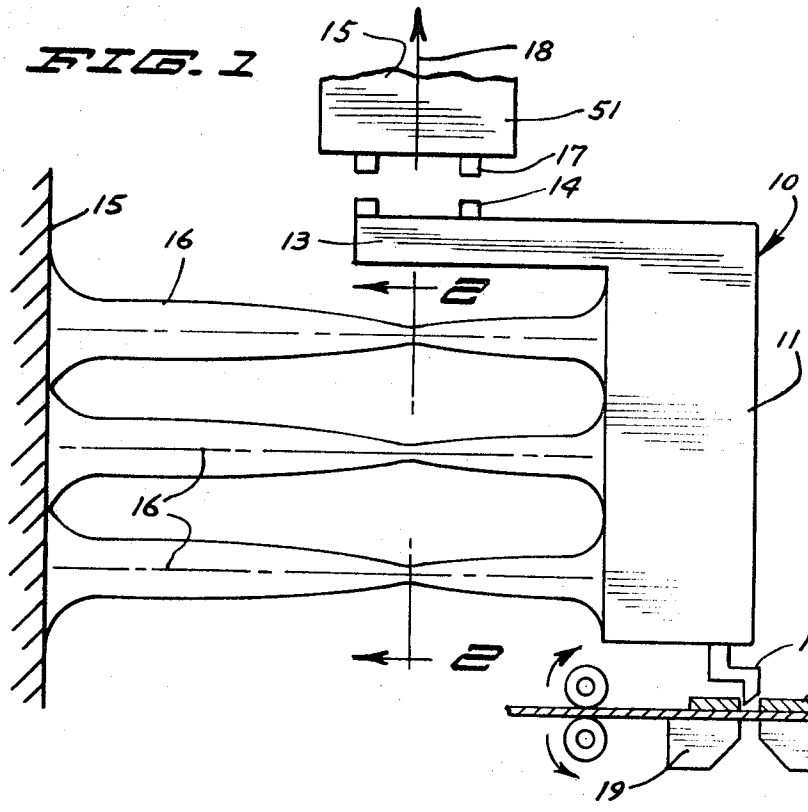


FIG. 1



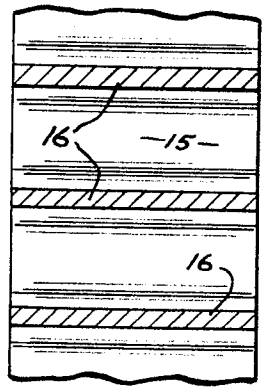


FIG. 2

FIG. 3

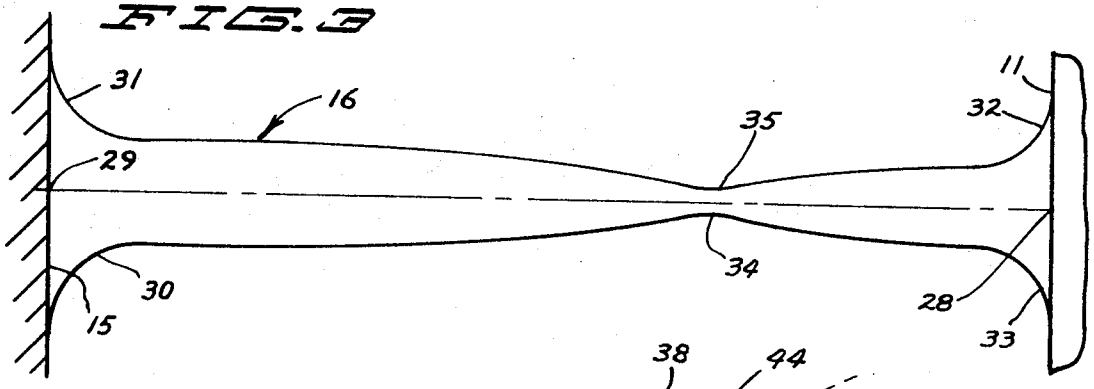
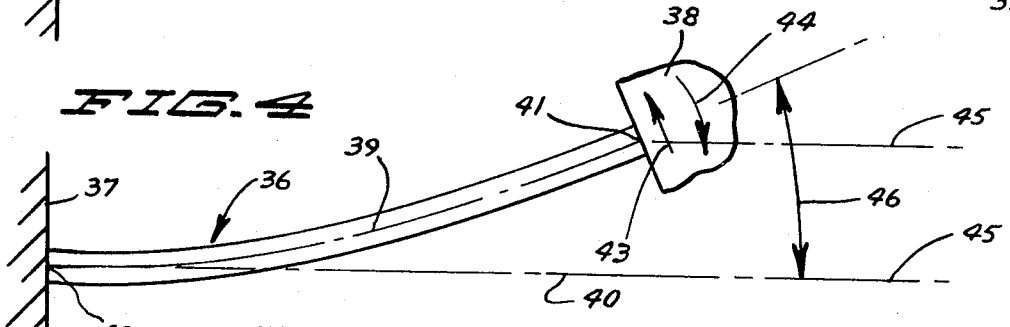


FIG. 4



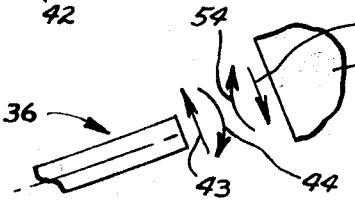


FIG. 5

INVENTOR.
DARRELL A. FROHRIB

BY

Burd Braddock & Bartz

ATTORNEYS

CONSTANT FLEXURE STRESS ENERGY STORING BEAM

CROSS REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of U. S. application Ser. No. 53,538, filed July 9, 1970, now abandoned.

BACKGROUND OF THE INVENTION

In the field of computers a wide variety of printing and punching devices are used as peripheral equipment for the printing and punching of computer cards or tape or the like. Computers and data processors are able to electronically feed data or other output signals at a rate substantially faster than the mechanical components of the peripheral equipment can be reliably actuated to record this output. Thus, a practical limitation is imposed upon the utilization of computers and high speed data processors by the speed of operation of the printing and punching mechanisms.

Generally, a printing or punching device can incorporate an impact element such as a print hammer or a punch key, biasing means, and means for holding the impact element against the urging of the biasing means. At the proper moment the holding means is released, and the energy stored by the biasing means is translated into kinetic energy of the impact element, enabling it to perform its impact function. Reduction in the size and the number of moving parts of a printing or punching mechanism generally results in a device having an increased speed capacity and greater reliability, for example the flexure spring punch of the U. S. Pat. No. 3,144,988.

It has been recognized as extremely advantageous to employ flexure elements as the biasing means for the loading of a print hammer or punch key or other impact element, thereby avoiding troublesome abrading mechanisms such as cams, helical springs, abrading pivots, and the like, for example see U. S. Pat. Nos. 3,460,753 and 3,447,455. Commonly, many conventional printing and punching devices store flexural energy in a flexural bundle comprised of one or more parallel slender beams connected at one end to a supporting frame and at the other end to an end mass, for example the print hammer unit of U. S. Pat. No. 3,359,921. To the mass is attached the printing or punching element, or other impact element to perform the desired impact function as, for example, in a wheel type printer where a hammer presses the paper against a wheel having print characters positioned along its periphery. Means are provided to deflect the mass, thereby deflecting the beams in a bending configuration and effecting the storage of flexural energy. Upon the release of the mass, the flexural energy stored in the beams is translated into kinetic energy enabling the impact element, upon impact, to perform the desired impact function. The flexural means are called upon for the storage and release of energy under high frequency impact conditions. Flexure beams of uniform cross section capable of withstanding such demanding use are inconveniently bulky and hence slower acting and not susceptible of the high speed operation capability of modern-day computers and data processors.

Typically, a flexure member is constituted as a slender beam of uniform transverse cross section. Upon deflection of such a beam in a bending configuration, the end forces and moments acting on the beam introduce

unequal, non-uniform stress along the length of the beam. Therefore, many sections of the beam are loaded to stress levels considerably below permissible design stresses. This results in excessive material volume for a prescribed flexural energy level over much of the length of the beam. The necessity of flexing this excessive material results in excessive power needs in the flexing means and in slower operating cycle times in the printer.

SUMMARY OF THE INVENTION

The invention relates to an improved impact output device such as a printing or punching head (for peripheral use, for example, with computers and high speed data processors) of the type actuated by flexural energy storing beams comprising a flexure bundle connected cantileverly to a parent structure at one end and supporting at the other end an end mass including an impact element such as a print hammer or punch key. In particular, the invention relates to an improved flexure beam having a contoured profile matched to an energy input in the form of a transverse load acting at a prescribed location on the flexure bundle. The profile of the beam is matched to the energy input so that under the prescribed loading conditions the maximum principal stress induced by the loading is virtually constant at all cross sections along the beam and occurs at the extreme outer fibers of the beam. Consequently less material is required for each flexure beam and the effective end inertia contributed by the beams is reduced to less than 50 per cent of that contributed by uniform flexure beams of uniform cross section. This reduction allows an increased cycling speed of the printing or punching operation, requires less power to flex the bundle, and causes less fatigue on the beams of the flexure bundle.

An object of the invention is to provide a flexure beam which under prescribed load conditions will have a constant maximum principal stress at every cross section along its length. A further object of the invention is to provide an optimized flexure beam structure for use in peripheral equipment with computers and high speed data processors, for example. A further object of the invention is to provide a flexural beam of reduced material volume and capable of higher operating frequencies. Further objects will become apparent upon the following description.

IN THE DRAWINGS

FIG. 1 is an elevational view of a computer punch head of the invention including a diagrammatic representation of a bundle of flexure beams of the invention;

FIG. 2 is a sectional view taken along the line 2—2 of FIG. 1;

FIG. 3 is an enlarged diagrammatic view of one of the flexure beams of FIG. 1;

FIG. 4 is a side elevation of a generalized slender beam in a bending configuration to illustrate the deflections of the beam and the end forces acting upon the beam; and

FIG. 5 is a side elevation of the beam of FIG. 4 separated from the end mass to further illustrate the end forces acting on the beam and on the end mass.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawings, there is shown in FIG.

1 a punch head, indicated generally at **10**, having an end mass **11**. Equal length flexure beams **16**, comprising a flexure bundle, are cantileverly attached at one end to a parent structure **15** and support at the other end the mass **11**. The flexure beams **16** of the invention are diagrammatically shown to have an optimized profile contour, as will be more fully described herein. As seen in FIG. **2**, the flexure beams **16** are of uniform transverse horizontal dimension. On one side the end mass **11** has an arm **13** extending inwardly toward the parent structure **15**. On the arm **13** is located a first set of electromagnetic contacts **14**. In alignment to receive the contacts **14** when the bundle is deflected and spaced apart from the contacts when the beams **16** are in an undeflected configuration, is a second set of stationary electromagnetic contacts **17** which are secured to an extension of the parent structure **15** as part of an electromagnet **51**. Upon energizing the electromagnet, there is created an electromagnetic attracting force, represented by the vector **18**, between the first contacts **14** and the second contacts **17**, which causes the end mass **11** to be deflected to and retained in a position where the two sets of contacts meet. In such a deflected state, the flexure beams **16** are in a bending configuration thereby storing flexural energy. For the reasons which will presently become apparent, in the embodiment of the invention as shown, the first set of contacts **14** are located on the arm **13** in a position such that the centroid of the attracting force **18** acts in a geometric plane which passes through the flexure beams **16** at a point one-third the length of the flexure beams **16** measured from the end mass toward the parent structure.

On the side of the mass **11** opposite the contacts **14** is a punch hammer **12**. In punching alignment with the punch hammer **12** are computer card feeding and holding means, which do not form a part of the present invention, but which include a punching die **19**, a stripper die **20** and feed rollers **21**. A computer card **22** rests on the punching die **19** between the punching die **19** and the stripper die **20**.

One of the flexure beams **16** of the invention is more particularly diagrammatically illustrated in FIG. **3**. The beam **16** has a profile contour optimized so that when flexure force is applied as shown in FIG. **1** the maximum principal stress is the same magnitude at every transverse cross section of the beam. The beam has an axial length l measured along the center line **27** of the beam between the point **28** where the flexure beam is attached to the end mass **11** and the point **29** where the beam is attached to the parent structure **15**. The beam has a transverse vertical dimension or thickness t_o which varies along the length l of the beam according to the optimized profile contour of the beam. For convenience the parameter t_o/l is designated by the term $\bar{t}_o$. A parameter x is defined as the distance starting at the point **28** along the center line **27** toward the point **29** and $\bar{x}$ is defined as said distance x divided by the length l. The functional relationship between $\bar{t}_o$ and $\bar{x}$ is represented as the thickness function, $\bar{t}_o(\bar{x})$. The thickness of the beam end attached to the parent structure at $\bar{x} = 1$ is represented as $\bar{t}_o(1)$. The profile of a beam is then described by the following profile equations:

$\bar{t}_o(\bar{x})/\bar{t}_o(1) = (3\bar{x} - 1/2)^{1/2}$ in the region $\frac{1}{3} + \Delta \leq \bar{x} \leq 1$

$\bar{t}_o(\bar{x})/\bar{t}_o(1) = (1 - 3\bar{x}/2)^{1/2}$ in the region $0 \leq \bar{x} \leq \frac{1}{3} - \Delta$

$\bar{t}_o(\bar{x})/\bar{t}_o(1) = (3\Delta/2)^{1/2}$ in the region $\frac{1}{3} - \Delta \leq \bar{X} \leq \frac{1}{3} + \Delta$

where

$\Delta = 3/32\ \bar{t}_o(1)^2$

The beam profile provided by the profile equations results in abrupt contour changes in the profile at the points $x = 0$, $\frac{1}{3} - \Delta$, $\frac{1}{3} + \Delta$, and 1. At these points of discontinuity there will arise stress concentrations. Such stress concentrations may be alleviated by any of several known engineering methods. For example, the addition of fillets **30, 31, 32** and **33** will relieve the stress concentrations at $\bar{x} = 0$ and $\bar{x} = 1$. At the points **30** and **31**, fillets having a radius of $\bar{t}_o(1)$, and at the points **32** and **33** fillets having a radius of $\bar{t}_o(0)$ will adequately relieve the stress concentration and will require the addition of very little material. In the region $\bar{X} = \frac{1}{3} - \Delta$ to $\bar{X} = \frac{1}{3} + \Delta$ the addition of fillets **34, 35** having a radius of 2Δ to smooth the profile in that region will adequately relieve the stress concentrations and will require the addition of very little material.

The derivation of the profile equations is best seen by considering FIG. **4** where there is shown a normally straight slender beam **36** in a bending configuration below the yield stress so as to follow Hooke's law. The deflection of the beam **36** is exaggerated for purposes of illustration. The beam is cantileverly attached at one end to a parent structure **37** and at the other end to an end mass **38**. It is understood that the beam **36** is one of a plurality of equal length beams attached at one end to the end mass **38** and to the parent structure **37** at the other end, in parallel relationship as the beams **16** of the flexure bundle of FIG. **1**. The center line of the beam **36** in the deflected state is represented by the line **39**, and in the undeflected state by the line **40**. The beam has an axial length l which is measured along the center line from the point **41** to the point **42**. For convenience, a parameter x is defined as the distance along the center line **39** from the point **41** toward the point **42**. In the deflected state there is acting on the beam at the end $x = 0$, end loads comprising a shear force F_o, represented by the vector **43**, and a bending moment M_o, represented by the vector **44**. The shear force **43** and the bending moment **44** are more fully illustrated in FIG. **5** where the end mass **38** is shown separated from the beam **36**. There is a reaction force, shown by the vector **53**, and a reaction moment, shown by the vector **54**, acting on the end mass **38** at the point of attachment of the beam **36**. As seen in FIG. **4**, each point on the beam center line in the deflected state is displaced from its position on the undeflected center line **40** in a direction perpendicular to the center line **40**, by a distance which is designated the displacement v_i for an arbitrary point i on the beam center line. The displacement v_i varies with the position of the point along the center line, so that it is expressed as functionally related to x, as $v_i(X)$. The displacement of the end point **41** of the beam is represented by the distance **45** and is, for convenience, termed v. In addition, at each arbitrary point i on the beam center line **39**, the center line is at an angle relative to the undeflected center line **40**, which is designated for convenience θ_i. Likewise, as the angle θ_i varies along the center line according to the position of the point i, a functional relationship may be expressed, as $\theta_i(X)$. The deflection angle at the end point **41** of the beam is shown as the angle **46** and is conveniently termed θ.

According to the well-known moment-curvature relationship for a beam in bending, the second derivative of the displacement with respect to axial distance x is equal to the bending moment acting on the beam at the "i"th section divided by the product of the modulus of elasticity of the beam material and the area moment of inertia of the "i"th section. This is mathematically expressed as:

$$\sigma^2 V_i/\sigma x^2 = M_{oi}/E\ I\ (x)$$

where M_{oi} is the moment acting at the "i"th section, E is the modulus of elasticity, and $I(x)$ is the area moment of inertia at the "i"th section. $I(x)$ is dependent upon the section geometry, hence the thickness function, and varies with x. Double integration of the moment-curvature equation for the beam **36**, and satisfaction of the boundary conditions that at $x = l$, $\theta(l) = 0$ and $V_i(l) = 0$, yields equations which are solved for the end loads F_o and M_o in terms of the end displacements θ and v as a function of the beam length, modulus elasticity and moment of inertia function. These equations represent the loading for which the optimized profile of the invention will give a constant maximum principal stress at any cross section of the beam.

The stresses in a beam in bending due to both external bending moment and transverse shear force inputs, for example beam **36**, are both tensile and shear. The tensile stress at a cross section acts parallel to the axis of the beam; the only significant shear component acts in the plane of the cross section of the beam and perpendicular to the principal axis. The maximum tensile stress in bending occurs at the outer fiber of the cross section and may be expressed as a function of the end loads acting on the beam, M_o and F_o , and the cross section geometry. As shown earlier, the end loads M_o and F_o are expressed in terms of integrals over the beam length. As an object of the invention is to define a profile whereby the maximum principal stress is constant, and assuming for the moment that the maximum tensile stress is the maximum principal stress, the first derivative with respect to x of the tensile stress function must equal 0. Having expressed the end loads in terms of integrals over the beam length, the solution of the first derivative equation yields the following solution for section geometry, in terms of the previous notation:

$$\tilde{t}_o\ (\tilde{x})/\tilde{t}_o\ (1) = (3\ \tilde{x} - 1/2)^{1/2}$$

in the region $\frac{1}{3} \leq x \leq 1$ and

$$\tilde{t}_o\ (\tilde{x})/\tilde{t}_o\ (1)\ (1 - 3\ \tilde{x}/2)^{1/2}$$

in the region $0 \leq x \leq \frac{1}{3}$

The solution also yields the following relationship of the end loads: $F_o\ l/M_o = 3$

thus dictating the prescribed loading location of FIG. **1**.

The above relationships were derived assuming that the maximum tensile stress was the maximum principal stress. This is true in regions governed by tensile stress, but is insufficient where shear stress governs as shown by the 0 thickness property provided by the foregoing relationships at $\tilde{x} = \frac{1}{3}$. An analysis of the shear forces acting on the beam shows that the shear stress is of a greater magnitude than the tensile stress in the region $\frac{1}{3} - \Delta \leq \tilde{x} \leq \frac{1}{3} + \Delta$, and the two are equal at the points $\tilde{x} = \frac{1}{3} - \Delta$ and $\frac{1}{3} + \Delta$, where Δ and $\tilde{x}$ are as previously defined. Therefore, in order to accommodate the shear stress the above profile relationships must be modified in the region $\frac{1}{3} - \Delta \leq \tilde{x} \leq \frac{1}{3} + \Delta$ by a segment having a thickness $\tilde{t}_o\ (\tilde{x}) = (3\ \Delta/2)^{1/2}$. The inclusion of fillets as described and illustrated earlier for the relief of stress concentrations caused by profile discontinuities results in the relationships governing the profile of the beam **16** as earlier presented.

In the use of the invention, referring to FIG. **1**, the electromagnet is energized, thereby creating the attracting force **18**, causing the displacement of the end mass **11** to a position where the contacts **14** meet the contacts **17**. The flexure beams **16** are then in a bending configuration and have a stored potential energy in the form of flexural energy. There is no unnecessary material on the beams **16** as the maximum principal stress along the length of each beam is constant. The amount of flexural energy stored in the flexure bundle is according to the function to be performed, and is a design parameter of the flexure bundle and the end mass. The feed rollers **21** guide a card **22** into the desired position between the punching die **19** and the stripper die **20**, in alignment with the punch hammer **12**. Upon de-energization of the electromagnet, the flexural energy in the beams **16** is translated into kinetic energy, and impact is effected by the punch hammer **12** upon the card **22**, leaving the correct perforation. The stripper die **20** holds the card in position as the punch hammer retracts. Because of the reduced mass of the flexure bundle and the end mass, the punching operation is performed at a higher frequency than could be previously achieved.

From the derived profile equations, as well as from FIG. **1**, it is apparent that the minimum thickness of the beams occurs at the point $\tilde{x} = \frac{1}{3}$, or at a point $\frac{1}{3}$ the length of the beams from the end mass attaching end to the parent structure attaching end. The beams of the flexure bundle, as shown by FIGS. **1** and **2**, are disposed in parallel facing relationship. The beams are optimized according to the thickness dimension rather than a transverse width dimension. Bending properties of a beam are more sensitive to thickness than to width. Optimization of a beam contour according to thickness is thereby more effective.

While there has been illustrated and described one embodiment of the invention, those skilled in the art will recognize further applications of the invention. For example, the punch hammer **12** could as well be a print key to perform a printing operation. Also in numerous devices such as electric typewriters there are required slender members which must operate at high frequency, and therefore be of minimum mass but able to absorb a maximum of energy. In such devices the flexure beam of the present invention would find application.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. An improved impact output device of the type having an end mass, an impact key attached to the end mass positioned to perform an impact function relative to a parent structure, at least two flexural energy storing members attached at one end to the end mass and cantileverly attached at the other end to said parent structure, and means for deflecting, holding and releasing said energy storing members to cause said impact key to perform said impact function, wherein:

said energy storing members are disposed in parallel facing relationship and each said flexural energy

storing member is a slender beam having an optimized contour profile of varying thickness matched to the energy input to the beam and having a minimum thickness at a point ⅓ the length of the beam from the end mass attaching end to the parent structure attaching end whereby the maximum principal stress at all points along the beam is the same when said deflecting means is operative to flex said beam.

2. The impact output device of claim 1 including:

stress relieving fillets at points of stress concentration on each said flexural energy storing member.

3. The impact output device of claim 2 wherein the means for deflecting the flexural energy storing members include:

means for electromagnetically deflecting said beams.

4. An improved impact output device for use with computers and data processors including:

an end mass;

an impact element attached to the end mass in a position to perform an impact function;

at least two flexural energy storing members attached at one end to the end mass and at the other end to a parent structure, each said member having a contour profile according to the equations:

$\tilde{t}_o(\tilde{x})/t_o(1) = (3\tilde{x} - 1/2)^{1/2}$ in the region $⅓ + \Delta \leq \tilde{x} \leq 1$

$\tilde{t}_o(\tilde{x})/t_o(1) = (1 - 3\tilde{x}/2)^{1/2}$ in the region of $0 \leq x \leq ⅓ - \Delta$

$\tilde{t}_o(\tilde{x})/\tilde{t}_o(1) = (3\Delta/2)^{1/2}$ in the region $⅓ - \Delta \leq x \leq ⅓ + \Delta$

and means for deflecting, holding and releasing said energy storing members.

5. The impact output device of claim 4 including:

stress relieving fillets at points of stress concentration on each said flexural energy storing member.

6. A flexural energy storing member including:

a slender beam for cantileverly attaching one end to a parent structure and for attaching the other end to an end mass, said beam having a contour profile of varying thickness optimized according to an energy input acting on a flexure bundle comprised of at least two of said members, said energy input in the form of a transverse load having a centroid acting in line with a point ⅓ the length of the beam from the end mass attaching end to the parent structure attaching end, said beam having a minimum thickness at said point ⅓ the length of the beam whereby the maximum principal stress along the beam is constant.

* * * * *

PO-1050
(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,742,800 Dated July 3, 1973

Inventor(s) DARRELL A. FROHRIB

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 4, line 1: $1/3 - \Delta \leq \tilde{x} \leq 1/3 + \Delta$,

$\hat{x}$ is lower case, not capital

Column 5, line 9: Equation should read:

$$\frac{\partial^2 v_i}{\partial x^2} = \frac{M_{oi}}{EI(x)}$$

Column 5, line 46: Equation should contain a closing bracket:

$$\hat{t}_o(\tilde{x})/\tilde{t}_o(1) = (3\tilde{x} - 1/2)^{1/2}$$

Column 5, line 18: "$V_i(\ell) = 0$" should be --$v_i(\ell) = 0$--.

Signed and sealed this 5th day of March 1974.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

57

PO-1050
(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,742,800 Dated July 3, 1973

Inventor(s) DARRELL A. FROHRIB

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 4, line 1: $1/3 - \Delta \leq \tilde{x} \leq 1/3 + \Delta$,

$\hat{x}$ is lower case, not capital

Column 5, line 9: Equation should read:

$$\frac{\partial^2 v_i}{\partial x^2} = \frac{M_{oi}}{EI(x)}$$

Column 5, line 46: Equation should contain a closing bracket:

$$\hat{t}_o(\tilde{x})/\tilde{t}_o(1) = (3\tilde{x} - 1/2)^{1/2}$$

Column 5, line 18: "$V_i(\ell) = 0$" should be --$v_i(\ell) = 0$--.

Signed and sealed this 5th day of March 1974.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents