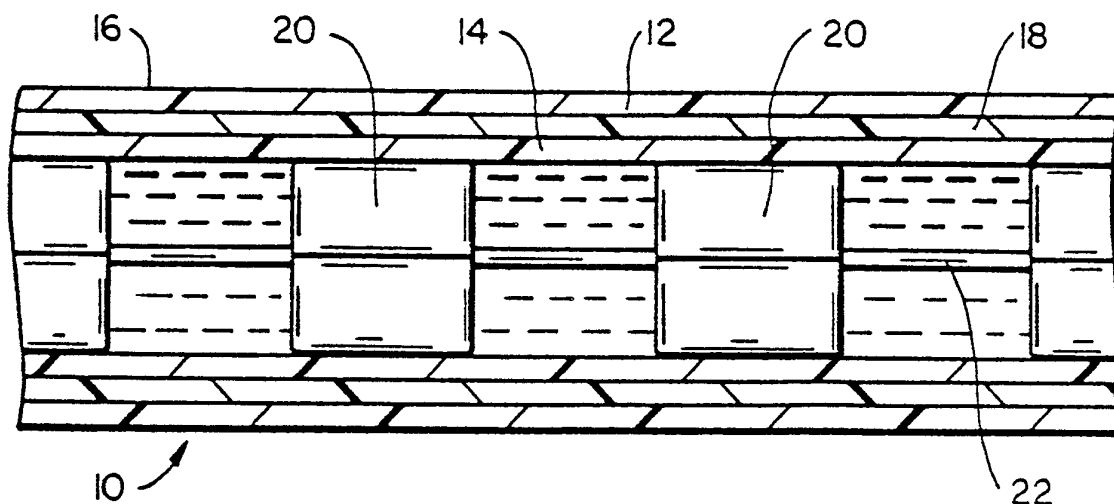




INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification⁴ : G01V 1/38	A1	(11) International Publication Number: WO 87/ 03379 (43) International Publication Date: 4 June 1987 (04.06.87)
(21) International Application Number: PCT/US86/02562 (22) International Filing Date: 26 November 1986 (26.11.86) (31) Priority Application Number: 802,507 (32) Priority Date: 27 November 1985 (27.11.85) (33) Priority Country: US (71) Applicant: RAYCHEM CORPORATION [US/US]; 300 Constitution Drive, Menlo Park, CA 94025 (US). (72) Inventor: KREVOR, David, Henry ; 151 Dolton Avenue, San Carlos, CA 94070 (US). (74) Agent: RICE, Edith, Anne; Raychem Corporation, 300 Constitution Drive, Menlo Park, CA 94025 (US).		(81) Designated States: AT (European patent), BE (European patent), CH (European patent), DE (European patent), FR (European patent), GB (European patent), IT (European patent), LU (European patent), NL (European patent), SE (European patent). Published <i>With international search report.</i>

(54) Title: TUBULAR ARTICLE



(57) Abstract

Novel laminate tubular articles (10) comprising an outer layer (12) having a modulus of at least about 10^7 Pascals, an interior layer (18) comprising a polymeric material having a loss tangent of at least about 0.5 at a temperature of from about 0°C to about 40°C at a frequency of from 10-4,000 Hz and whose modulus is less than the modulus of the outer layer and an innermost layer (14) having modulus greater than the modulus of said interior layer. The invention further relates to a device for sensing in a body of water, said device comprising at least one sensor (20) surrounded by the novel laminate tubular articles of the invention. The mechanical and acoustic properties of the article make it particularly appropriate for use as the hose in a towed-array sonar system.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	FR	France	ML	Mali
AU	Australia	GA	Gabon	MR	Mauritania
BB	Barbados	GB	United Kingdom	MW	Malawi
BE	Belgium	HU	Hungary	NL	Netherlands
BG	Bulgaria	IT	Italy	NO	Norway
BJ	Benin	JP	Japan	RO	Romania
BR	Brazil	KP	Democratic People's Republic of Korea	SD	Sudan
CF	Central African Republic	KR	Republic of Korea	SE	Sweden
CG	Congo	LI	Liechtenstein	SN	Senegal
CH	Switzerland	LK	Sri Lanka	SU	Soviet Union
CM	Cameroon	LU	Luxembourg	TD	Chad
DE	Germany, Federal Republic of	MC	Monaco	TG	Togo
DK	Denmark	MG	Madagascar	US	United States of America
FI	Finland				

-1-

TUBULAR ARTICLE

The invention relates to a novel tubular article exhibiting constrained layer damping, and to a device comprising one or more hydrophones surrounded by said tubular article, said device being useful for towing behind a vessel at sea as a towed-array sensor system.

It is desirable to enclose articles such as electronic devices, transmitters, receivers or sensing instruments, (e.g. hydrophones used in sonar) in a tube which will protect them from the effects of water. Such tubing, which may be 100 meters or more in length, can then be used to make readings when towed by a vessel in the open sea. Typically, hydrophones are packed into a semi-rigid tube typically 1 to about 4 inches (2.5 to 10 cm) in diameter. The tubing is loaded with an acoustically transparent material such as oil through which sound may propagate and which may add buoyancy. The hydrophones are fixed in place by tying each of the string of hydrophones to the tube and sealing the tube.

This entire assemblage is typically known as a "towed-array" and is used as the sensing portion of a sonar system for both civilian and military applications.

It will be readily apparent that a high sensitivity of detection is desirable and that since this sensitivity

-2-

is partly determined by the signal-to-noise ratio reaching the hydrophones, it is advantageous to reduce the acoustic noise generated within or by the array. As the array is pulled through the water, noise is generated from three separate mechanical excitations. The first is towline excitation originating either at the vessel or as towline strumming due to vortex shedding. The second is a tail end effect; array tension is low and the array may be susceptible to "snaking" instability. The third, and most important, noise source is the turbulent boundary layer (TBL) which develops as the array is drawn through water. The way in which the TBL creates noise is by generating bulge waves and/or extensional waves (either resonant or non-resonant) in the hosewall. The entire success of towed arrays depends on the isolation of the hydrophones from these surface pressures (whose spectral level increases as the fourth power of speed).

It is desirable, then, to use a tubing which provides for maximum transmission of the acoustic signals that the sensors are attempting to detect but which minimizes the noise created by the array and minimizes transmission of the noise. Two major properties of the material selected for tubing affect its acoustic properties. One property of material that significantly reduces noise is its ability to exhibit high mechanical damping. A second major property of the tubing is that it should not be too flexible, (i.e. should not have a low modulus) as this will more

-3-

readily encourage the generation of bulge waves due to the TBL. This problem is further exacerbated by the fact that towed array tubes are limited in their wall thickness due to the size of the hydrophones, the degree of difficulty in towing large diameter tubing and the need to be radially compliant to permit it to be easily coiled for stronger handling purposes. Stiffness, therefore, due to wall thickness can not be changed to a great degree. Secondary considerations include the density of the material, abrasion resistance, resistance to the fill fluids and water, low temperature flexibility, creep resistance, the ability to take a good surface finish, and the ability to be manufactured in continuous lengths.

Compositions that have been used for jacketing sonar detection arrays include plasticized polyvinyl chloride (PVC) and various rubbers, e.g. butyl rubber and nitrile rubber. However, while the elastomers have high mechanical damping, the elastomers suffer from disadvantages such as poor processing characteristics (especially for long lengths), poor abrasion resistance, insufficient stiffness, excessive weight and insufficient solvent resistance. Plasticized PVC can be easily processed, but is too stiff at low temperatures and the plasticizer is leached out by the acoustic fluids. Further the elastomers tend to be of relatively low modulus and thus tend to flex more often resulting in the creation of more noise. One method to achieve a balance between modulus and damping effects

has been to blend an acoustic damping material with a material of higher modulus. However, these materials tend to be difficult and expensive to process into continuous tubing lengths.

In U.S. Patent No. 4,410,012, a line array hose is described comprising a tube of soft flexible, thermoplastic material having high damping characteristics and a plurality of raised longitudinal ribs. The construction is described as having good self-noise damping properties and improved resistance to mechanical abuse. However, the raised longitudinal ribs cause an increased turbulence and noise at the TBL. Additionally, the hose is made of PVC and therefore has a high specific gravity.

U.S. Patent No. 3,729,919 discloses a multi-layer drag rope for towing submarine measuring equipment. The layers comprise polyamide and polyurethane, and the polyamide is in mesh form. The rope has the function of vibration isolation, and to allow it to carry out this function it must be capable of stretching. No constrained layer damping is provided, and the rope would not be useful for providing damping around hydrophones.

In commonly assigned U.K. Application No. GB 2,123,011A, incorporated herein by reference, compositions comprising a segmented urethane block polymer and an elastomer having a glass transition

temperature between -40°C and $+15^{\circ}\text{C}$ are described. These compositions maintain relatively high damping values of the elastomer while increasing modulus values.

It has been surprisingly found that a tubular article exhibiting constrained layer damping is of particular use as an acoustic module for a towed array sonar system. Good damping characteristics are provided while maintaining a high modulus and processability at relatively low cost.

The invention therefore provides a tubular article exhibiting constrained layer damping comprising:

- (a) an outer layer comprising a polymeric material having a modulus of at least about 10^7 Pascals;
- (b) an interior layer comprising a polymeric material having a loss tangent of at least about 0.5 at a temperature of from about 0°C to about 40°C and at a frequency of from 10-4,000 Hz and a modulus less than the modulus of the material of the outer layer; and
- (c) an inner layer having a modulus 10^7 - 10^{10} Pascals, said modulus being greater than the modulus of said interior layer;

said layers being joined together to form a laminated tubular structure in which substantially all of the interior layer is constrained due to its lamination to the inner and outer layers.

The tubular article may additionally comprise further layers on the outside or inside or on both of those mentioned. Also, the interior layer may itself comprises more than one layer.

The invention also provides a device capable of use as at least part of an acoustic module of a towed array sonar system, which comprises

- (a) the article of the invention;
- (b) at least one hydrophone within the article; and optionally
- (c) an acoustically transparent material within the article.

The device of the invention may be connected to a vibration isolation module that may reduce vortex shedding and turbulent boundary layer noise. The device of the invention may be towed by means of the vibration isolation module, which should be capable of some elastic longitudinal extension. The device of the invention (in which any hydrophone will be located) is

however preferably longitudinally substantially inextensible.

The invention is further illustrated by the accompanying drawings, in which:

Figure 1 illustrates the tubing in accordance with this invention being used for sonar measurements.

Figure 2 is a longitudinal cross-section view of an embodiment of the tubing in accordance with this invention.

Figure 3 is a horizontal cross-section view of an embodiment of the tubing.

Figure 4 is a horizontal cross-section view of an embodiment of the tubing wherein the inner surfaces of the tubing are not parallel.

Fig. 5 is a horizontal cross sectional view of an embodiment of the tubing showing additional interior and inner layers.

Fig. 6 is a graph showing the relative damping of HDPE/VAE laminates at 16 Hz.

Fig. 7 is a graph showing the effect of interior layer thickness on damping of three layer construction.

A towed array sonar system typically comprises an acoustic module housing a plurality of hydrophones towed by means of a cable or rope behind a vessel. A vibration isolation module may be provided between the towing rope and the acoustic module in order to eliminate or to damp out vibration. The rope itself may have this vibration damping ability. The acoustic module should provide viscoelastic damping in order that the hydrophones produce an intelligible signal. The invention ensures this by making use of the phenomenon of constrained layer damping.

As indicated above, the article of the invention comprises three layers, namely an interior damping layer, and two constraining layers, as follows. Polymeric material for making the interior layer or layers of the laminated tubular article of this invention comprises polymers which exhibit good physical properties (such as high modulus, solvent and water resistance, low specific gravity, abrasion resistance, flexibility, ultraviolet stability, good weatherability, scrape resistance, good (i.e. smooth) surface finish, creep resistance), as well as acoustic damping characteristics. These polymers should have a loss tangent of at least 0.5 at a temperature of from about 0°C to about 40°C at a frequency range of 10 to 4000 Hz. Preferably the loss tangent is at least 1.0, and preferable the given values of loss tangent apply in the temperature range 0°C to 30°C. Loss tangent ($\tan \delta$) is the ratio of the loss modulus to

storage modulus and is measured by means of tension pendulus apparatus as described in ASTM-D-2236. See Great Britain Patent No. 1,317,814 for a discussion and representative list of some polymers for damping use. Preferred polymers include elastomers such as ethylene/vinyl acetate copolymers, acrylonitrile/butadiene copolymers, butyl rubber, nitrile rubber, ethylene/vinyl acetate/methacrylic acid terpolymers, neoprene rubber, chlorinated polyethylene, chlorosulfonated polyethylene, fluorocarbon elastomers (e.g. Viton from DuPont), ethylene/propylene copolymers, styrene/butadiene copolymers, polyester elastomers (e.g. Hytrel from DuPont), polyurethane and nitrile/PVC blends, and other blends of two or more of the above.

Additives may be included in the polymeric material selected for the interior layer or layers. Additives may be selected to impart a desired property such as increased stiffness, specific gravity improved tensile strength, improved weatherability, increased viscosity during fabrication, etc. Additives include carbon black, graphite, talc, clays, calcium carbonate, mica, silica, glass, antimony oxide, etc. Further, reinforcing means such as fibers may be added to improve dimensional stability, especially longitudinal strength such as fibers made of nylon, dacron, Kevlar, glass (fiber glass), graphite, high-oriented polyethylene fibers, ceramic fibers and cellulosic fibers. Agents which can enhance crosslinking can also

-10-

be added such as diallyl allyl phosphonate; triallyl phosphate; trimethylol propane trimethacrylate; triallyl cyanurate; triallyl isocyanurate; tetraethyleneglycol dimethacrylate; and phenylene dimaleimide. Further, the polymeric material should be substantially void-free to reduce acoustic problems caused by such voids.

The interior layer's or layers' wall thickness preferably is at least 0.01" (0.025 cm) and preferably is between about 0.05" and 0.2" (0.127 and 0.508 cm).

The outer layer or layers comprises a polymeric material. The polymeric material has a Young's modulus of at least 10^7 Pascal and preferably between about 10^7 and 10^9 Pascal. Young's modulus is measured by ASTM E756. The modulus may be increased as desired by crosslinking. The polymeric material selected may be a thermoplastic or an elastomer as desired. The polymer may also have desirable damping characteristics although this is not necessary. The polymer of the outer layer should be compatible with the environment it is to be used in. That is, it should be resistant to aqueous conditions and to saline conditions where applicable. It is also desirable that the outer layer be abrasion resistant and easily laminated to the interior layer. It is further preferred that the layer(s) be substantially void-free. A preferred thickness of the outer layer is at least about 0.01 inches (0.025 cm) and preferably from about 0.015 to

-11-

about 0.040 inches (0.038 to about 0.1 cm) thick. The outer surface of the outer layer should be relatively smooth and should be substantially circular if it is the outermost layer of the article. The inner surface need not be smooth nor its cross-section circular (Fig. 4). Rather, its shape should be compatible with the interior layer's surface. Preferred materials are the thermoplastic polymers and in particular thermoplastics such as high density polyethylene, low density polyethylene, PVC, EVA, polyvinylidene fluoride, polyurethane, ethylene/ethyl acrylate copolymers, vinylidene fluoride/ethylene copolymers, ethylene/vinyl acetate copolymer, ionomers (e.g. Surlyn from DuPont), polyphenylene oxide, liquid crystalline polymers and nylon. Additives reinforcing means and crosslinking agents may be included in the same manner as previously described for the interior layer. Where more than one outer layer is used they may be of the same or different materials.

The inner layer or layers comprise a material having a modulus greater than the modulus of the interior layer. The Young's modulus of the inner layer(s) is preferably at least 10^7 Pascal and preferably between about 10^8 Pascal and 10^9 Pascal. The inner layer(s) are preferably of a polymeric material. The polymer may be selected from the list for the outer layer being either the same or different than that used for the outer layer and may be the same or different when there is more than one inner layer (Fig. 5). In either event,

the polymeric material preferably has a modulus between 10^7 and 10^9 Pascal, etc. and may include additives and reinforcements. The innermost inner layer may also comprise an outermost layer of the sensor (e.g. hydrophone). The outer surface of the inner layer may be rough or vary in thickness in order to conform to the interior layer.

An inner and outer layer is positioned on either side of an interior layer and laminated thereto by any convenient means. Any additional layers may be similarly applied. For example, polymeric inner and outer layers may be coextruded with the polymeric material of the interior layer. Another example to laminate the layers is to have each layer sequentially extruded. Another example comprises positioning inner and outer layers of a polymeric material on the inner and outer surface of a preformed tubular interior layer and bond them thereto by heat and pressure, a suitable adhesive, or by chemical means, such as crosslinking by chemical means (for example with the aid of cross-linking promoters) or by irradiation. In another embodiment, the individual layers are laminated together to form the article by dimensional recovery techniques (i.e. a given layer in a dimensionally unstable form is positioned over another layer respectively and recovered thereon for example, by heat recovery). In a still further embodiment, the tubular layers may be formed by wrapping sheets of the appropriate material into the desired shape. Adhesion

between layers may be further aided by selecting those compositions for the layers which are compatible such that an interaction occurs on heating of the layers. In any event, it is preferred that the laminated layers have a bond strength of at least about 3 lbs/linear inch (0.54 Kg/linear cm).

In another embodiment of the invention, additional layers may be placed on the outside or inside of the tubular article. So, for example, additional layers could be placed on the innermost surface of the inner layer or the outermost surface of the outer layer of the article to provide desired benefits such as mechanical protection, compatibility with water or buoyancy fluids, means for towing, etc. Further, additional layers may comprise an additional interior layer and inner layer or interior layer and outer layer (see Fig. 5) to yield additional damping characteristics.

Only the outer surface of the outer layer (the outermost outer layer when there is more than one outer layer) need be circular. The inner and outer surface of the interior layer(s) need not be parallel in its horizontal cross-section. Both the thickness of the wall as well as the shape of said layers may vary as needed (e.g. to improve adhesion between layers, improve acoustics, reduce the cost of material, provide a means for introducing reinforcing fibers, etc.) (see Fig. 4).

The materials and dimensions of the various layers are selected such that the laminated tubular article preferably has a Young's modulus between about 10^7 and 10^9 Pa, and a loss tangent of at least 0.3 in the range of 0-40°C and 10-4,000 Hz. Typical dimensions for such tubular article in its recovered condition where appropriate are an outer diameter of 1 to 4 inches (2.5 to 10 cms) and a total wall thickness of from about 0.080 to 0.400 inches (0.2 to 1.0 cm). Further, it is preferred that the tubular article be of a specific gravity of between about 1.0 to 1.10 to aid in the buoyancy of the tubular article plus sensing device. The entire article may be made dimensionally recoverable by conventional techniques. For example, the article may be subjected to radiation cross-linking from an appropriate source. The article may then be expanded to a dimensionally unstable form and then recovered to its original shape by heating as desired.

The hydrophones or other sensing devices may then be positioned inside the laminated tubular article along with a buoyancy fluid such as an isoparaffinic petroleum solvent (e.g. Isopar M from Exxon) where appropriate. In one method, the laminated tubular article is made dimensionally recoverable to facilitate positioning of sensing devices therein. The sensing device may be positioned inside a laminated tubular article which is in an expanded dimensionally unstable form and recovered around such devices to reach a dimensionally stable form. The tube is then sealed

-15-

from the environment. The tube may then be attached to a vibration isolation modulus to insulate the sensing devices from towline excitation. A coupling device is connected to both the tubular article and the vibration isolation module by the load bearing members (e.g. reinforcing fibers) of each and then potted with epoxy or the like to maintain the connection.

The superior performance of the tubular article is due to the constraining effect of the inner and outer layers on the inner and outer surfaces of the interior layer (or layers). Accordingly, the interior layer is comprised of a high-damping material. Substantially all of the surface of the interior layer (preferably greater than about 99%) is constrained due to its lamination to the inner and outer layers, therefore interior (intralayer) deformation of the interior layer is dominated by shear rather than constriction and dilation. The resultant damping is greater than for a similar two-ply structure, where about 50% of the total surface area of the high-damping material is free (i.e. unconstrained). For example, a three-ply construction of plastic (thickness "x")/elastomer (thickness "y")/plastic (thickness "x") would have higher damping characteristics than the analogous two-ply construction of plastic (thickness "2x")/elastomer (thickness "y") even though both systems have the same total thickness of each of the two materials.

For the total construction of the article therefore, both high damping and high modulus can be achieved and

can be varied depending upon the geometry of the system (i.e. relative thicknesses of the layers) and the materials used. Because the article of the invention does not require a single compound or mechanically stable blend to meet all acoustic and mechanical criteria, much more latitude and freedom exists in the choice of materials of the present invention thus is a further advantage over the prior art hoses. The interior layer provides damping (enhanced by the phenomenon of constrained-layer damping). The inner and outer (constraining) layers provide high modulus, and the materials comprising the inner and outer layers may be varied independently according to specific environmental requirements (for example, the outer layer need a high-quality surface to minimize hydrodynamic noise whereas the inner layer may require oil-resistance to withstand the organic fill-fluid). Additionally, the system is adaptable to different modulus/damping requirements by modification of layer thicknesses or materials. Different levels of modulus or damping may be chosen according to factors such as tow speed, ambient temperature (arctic or tropics deployment) or acoustic frequency range of interest.

With reference to the drawings, wherein like reference characters designate like or corresponding parts throughout the views, in Figure 1 there is shown a device in accordance with this invention generally indicated by 10, towed by a vessel 8 in the open sea and having vibration isolation module 6 attached to an

acoustice module, and by means of which it is towed. The vibration isolation module isolates the acoustic module from, for example, vibration due to tow-line strum.

As shown in the longitudinal section of Figure 2 and the cross-section of Figure 3, tubular article 10 for enclosing a plurality of hydrophones 20 connected by connector 22 and comprises an interior layer polymer 18 is laminated on its outer surface by outer layer 12 and on its inner surface by inner layer 14 wherein the outer surface of the outerlayer 16 is smooth and circular.

In figure 4 the tubular article is shown with the outer surface of layer 12 being circular and with additional fiber reinforcements 24.

In figure 5 an embodiment of the invention is shown wherein additional layers outermost 26 and a further interior layer 18 placed on the article illustrated in Fig. 3 giving a 5-layer construction.

The phenomnom of a three-layer article of this invention is illustrated in Figure 6. The figure shows an effect of viscoelastic damping for three samples as a function of temperature at 16 Hz. Measurements were made in the torsional mode with a Rheometrics RMS-680 Mechanical Spectrometer. The three samples were all of identical length, width and thickness (63.5 mm x 12.7

mm x 1.52 mm) and the overall composition of each composite sample was identical (50% high-density polyethylene [HDPE] and 50% elastomeric ethylene/vinyl acetate [VAE] copolymer).

Sample "a" is an intensively mixed, macroscopically homogeneous, blend of HDPE and VAE. The beam is a single-ply, mechanically stable blend. Sample "b" is a two-ply laminate where one layer is HDPE and the other is VAE. Samples "a" and "b" do not embody the invention.

Sample "c", which embodies the invention, is a three-ply laminate of HDPE, VAE and HDPE where the VAE layer is "sandwiched" in-between two HDPE layers. The thickness of the VAE layer in beam "c" is the same as the VAE layer in sample "b". The thickness of each of the HDPE layers in sample "c" is one-half the thickness of the HDPE layer in "b". In each case the HDPE was Phillips Marlex 5202 (trade mark), the VAE was Wacker VAE 711 (trade mark), and they were used in a ratio of 1:1 by weight.

Figure 6 illustrates that sample "c" exhibits significantly higher damping than sample "b" which is higher than sample "a". As each sample is of identical size, shape and overall composition, this is due to geometrical construction. The superior damping of sample "c" appears to be due to the aforementioned phenomenon of constrained-layer-damping.

Examples

Of the following twenty-six examples, results of the first three are illustrated in Figure 7 to show the effect of interior-layer thickness on overall damping. Examples 1, 2 and 3 are of the same materials and differ primarily in the relative thicknesses of the layers. Figure 7 shows that the greater the thickness of the interior (damping) layer, the higher the overall damping.

The examples in general illustrate the invention and are not intended to be limiting. One skilled in the art, after reading the specification, would be able to substitute materials, additives, reinforcements and blends thereof and the like.

It should be stated that, whereas in the examples the outer and inner (constraining) layers are both made from the same plastic or plastic blend, it is not necessary for the outer and inner layers to be of the same material. Indeed, for many applications, it is highly desirable for the inner and outer layer to be of different materials. This is particularly true where the inner and outer layers would be exposed to different chemical environments (e.g. organic oil and aqueous saline respectively).

In the following examples, various laminates of the following materials were tested.

-20-

- A modified high-density polyethylene (Plexar 5970)
- B ethylene/vinyl acetate copolymer 45%
nitrile rubber (Paracril) 45%
graphite 10% blend
- C low-density polyethylene
(DYNH-1)
- D ethylene/vinyl acetate copolymer, 90%
graphite 10%
- E high-density polyethylene
(Marlex 5202)
- F ethylene/vinyl acetate copolymer
(VAE 711)
- G nitrile rubber
(Paracril CLT)
- H modified EVA resin (Plexar 3)
carbon black (3%) blend
- J ethylene/vinyl acetate copolymer
ethylene/vinyl acetate/methacrylic acid
terpolymer (Elvax 4320) (10%)
carbon black (3%) blend

- K ethylene/vinyl acetate copolymer
ethylene/vinyl acetate/methacrylic acid
terpolymer (10%)
talc (10%)
carbon black (3%) blend
- L ethylene/ethyl acrylate copolymer (DPD 6169)
ethylene/vinyl acetate/methacrylic acid
terpolymer (10%) (Elvax 4320)
carbon black (3%)
- M modified EVA copolymer
(Plexar 3)
- N ethylene/vinyl acetate copolymer
(high vinyl acetate content)
- P ethylene/ethyl acrylate copolymer (DPD 6169)
carbon black (3%) blend

Example 1-20

In Examples 1 to 16 a planar 3-ply laminate of the compositions used in the invention was tested for modulus and loss tangent (Tan δ) with results as follows (ASTM D1876). The planar laminates were made by compression molding using a conventional temperature-controlled hydraulic press (e.g. manufactured by Pasadena Hydraulics Inc.).

Examples 17 to 20 are comparative examples, where the same relative amounts of polymers were used, but in a 2-ply laminate.

The following table gives the maximum value of $\tan \delta$, the temperature at which it occurs, and the modulus at that temperature.

-23-

		3-ply Laminate (Normalized Relative Thickness)		Modulus (Pa) at (Tan δ) max		Temp (°C) at (Tan δ) max
Total Thickness"	Example	Thickness	(Tan δ) max	at (Tan δ) max		
.094	1	A(.357)/B(.319)/A(.323)	.563	2.74e8		11
.076	2	A(.242)/B(.528)/A(.230)	.690	8.02e7		12
.100	3	A(.178)/B(.655)/A(.168)	.812	1.18e8		12
.060	4	C(.294)/D(.400)/C(.305)	.577	1.59e8		15
.081	5	C(.247)/D(.506)/C(.247)	.580	1.62e8		16
.104	6	C(.191)/D(.610)/C(.199)	.721	9.38e7		17
.060	7	C(.294)/B(.396)/C(.310)	.547	1.50e8		11
.081	8	C(.258)/B(.514)/C(.228)	.592	1.36e8		13
.121	9	C(.16)/B(.53)/C(.31)	.667	1.05e8		13
.090	10	E(.194)/F(.579)/E(.227)	.795	1.33e8		11
.090	11	E(.228)/G(.534)/E(.238)	.850	1.53e8		1
.081	12	C(.291)/F(.452)/C(.257)	.813	1.02e8		9
.089	13	H(.24)/J(.52)/H(.24)	.685	9.73e7		10
.089	14	H(.24)/K(.52)/H(.24)	.689	1.02e8		16
.089	15	L(.24)/J(.52)/L(.24)	.605	4.10e7		17
.089	16	H(.24)/F(.52)/H(.24)	.875	7.69e7		12

		2-ply Laminate (Normalized Relative Thickness)		Modulus (Pa) at (Tan δ) max		Temp (°C) at (Tan δ) max	Correspo 3-ply E
Total Thickness"	Example	Thickness	(Tan δ) max	at (Tan δ) max			
.090	17	E(.50)/F(.50)	.538	1.78e8	7		10
.090	18	E(.473)/G(.527)	.546	2.47e8	-1		11
.090	19	H(.50)/F(.50)	.714	1.30e8	8		16
.100	20	C(.50)/F(.50)	.700	1.32e8	7		12

All data at 30 Hertz.

Example 21

The effect of irradiative cross-linking is shown in the following table. Results are shown for pairs of layers, but the bond strengths given are applicable when relevant interfaces occur in three-layered structures.

<u>Layers</u>	<u>Beam Agent Added</u>	<u>Pounds (force) per linear inch (Kg/cm</u>	
		<u>Unirradiated</u>	<u>To Separate Irradiated</u>
F/C	no	0.22 ()	0.32 ()
F/M	no	0.43 ()	0.84 ()
D/A	no	0.66 ()	1.65 ()
N/H	yes	1.60 ()	4.17 ()
N/L	yes	2.56 ()	3.81 ()
N/P	yes	2.89 ()	4.38 ()
J/M	yes	2.31 ()	4.41 ()
K/M	yes	3.37 ()	6.09 ()

Examples 22-26

The following 3-ply hoses were made by extruding on Davis Standard (single-screw) extruders (2½" (6.4 cm), 24:1 for the plastic; 2½" (6.4 cm), 20:1 for the elastomer) at temperatures of 200 to 320°F (93.3-160°C) for the elastomers and 210 to 330°F (99-165°C) for the plastic. Ingredients for each layer were premixed using a Banbury (30 lb., 66 Kg) intensive mixer until homogeneous. The plastic was then pelletized. The elastomer was milled and cut into 1-2½ inch (2.5-6.4 cm) wide strips for use in the rubber extruder. Satisfactory articles of the invention resulted in each case.

-25-

Example 22

Interior layer - 0.060-0.077 inches (0.15-0.18 cm) thick
Vinyl acetate/ethylene copolymer (high VA content) 89%
Graphite 10%
Crosslinking Agents 1%
Inner layer and outer layer each 0.019-0.035 inches
(0.05-0.09 cm) thick
Low density polyethylene

Example 23

Interior layer 0.055-0.072 inches (0.14-0.18 cm) thick
Nitrile rubber 44.5%
Vinyl acetate/ethylene copolymer (high Va content) 44.5%
Graphite 10%
Crosslinking agents 1%
Inner and outer layer each 0.019-0.034
(0.05-0.09 cm) inches thick
Low density polyethylene

Example 24

Interior layer - 0.071-0.095 inches (0.18-0.24 cm) thick
Ethylene-propylene-diene (EPDM) rubber
Inner and outer layer each 0.019-0.034 inches
(0.48-0.09 cm) thick
Low density polyethylene

-26-

Example 25

Interior layer 0.015-0.040 inches (0.38-0.1 cm) thick	
Ethylene/vinyl acetate copolymer (high VA content)	79%
Ethylene/vinyl acetate/methacrylic acid terpolymer	9%
Talc	9%
Carbon black	2%
Crosslinking agent	1%
Inner and outer layer each 0.010-0.070 inches (0.25-0.18 cm) thick	
Modified ethylene/vinyl acetate copolymer (low VA content)	88%
Carbon black	2%
Crosslinking agent	1%

Hoses of Example 25 were made both with and without longitudinal reinforcement fibers in the interior layer.

Example 26Interior layer

0.030-0.060 inches (0.08-0.16 cm) thick	
Ethylene/vinyl acetate copolymer (high VA content)	83%
Ethylene/vinyl acetate/methacrylic acid terpolymer	8%
Talc	8%
Cross-linking agent	1%

Inner and outer layer

0.015-0.035 inches (0.04-0.09 cm) thick	
Modified ethylene/vinyl acetate copolymer (low	

-27-

VA content)	87%
Ethylene/vinyl acetate/methacrylic acid terpolymer	10%
Carbon black	2%
Cross-linking agent	1%
with longitudinal fiber reinforcement	

-28-

We claim:

1. A tubular article exhibiting constrained layer damping comprising:

- (a) an outer layer comprising a polymeric material having a modulus of at least about 10^7 Pascals;
- (b) an interior layer comprising a polymeric material having a loss tangent of at least about 0.5 at a temperature of from about 0°C to about 40°C and at a frequency of from 10-4,000 Hz and a modulus less than the modulus of the material of the outer layer; and
- (c) an inner layer having a modulus of from at least 10^7 to 10^{10} Pascals, said modulus being greater than the modulus of said interior layer;

said layers being joined together to form a laminated tubular structure in which substantially all of the interior layer is constrained due to its lamination to the inner and outer layers.

2. A tubular article according to claim 1, in which greater than 99% of the interior layer is constrained due to its lamination to the inner and outer layers.

3. A tubular article according to claim 1, which is dimensionally recoverable.

-29-

4. A tubular article according to claim 1, 2 or 3, wherein the inner and outer layers each comprise a low density polyethylene, high density polyethylene, ethylene vinyl acetate, or a blend of ethylene/ethyl acrylate copolymer and ethylene/vinyl acetate/methacrylic acid terpolymer, the inner and outer layers being the same or different.

5. A tubular article according to any preceding claim, wherein the interior layer comprises ethylene/vinyl acetate copolymer, nitrile rubber, ethylene/vinyl acetate/methacrylic acid terpolymer, or EPDM rubber, or a blend of two or more thereof.

6. A tubular article according to any preceding claim, whereby interlayer adhesion is enhanced by cross-linking.

7. A tubular article according to any preceding claim, in which each of layers (a), (b) and (c) is extruded.

8. A tubular article according to any preceding claim having the form of a flexible hose.

9. A device capable of use as at least part of an acoustic module of a towed array sonar system, which comprises:

(a) an article according to any preceding claim; and

(b) at least one hydrophone within the article.

10. A device according to claim 7, which additionally comprises:

-30-

- (c) an acoustically transparent material within the article.

1/4

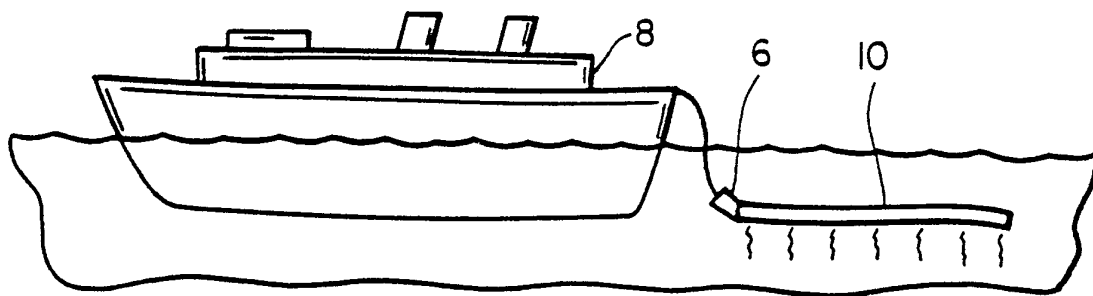


FIG_1

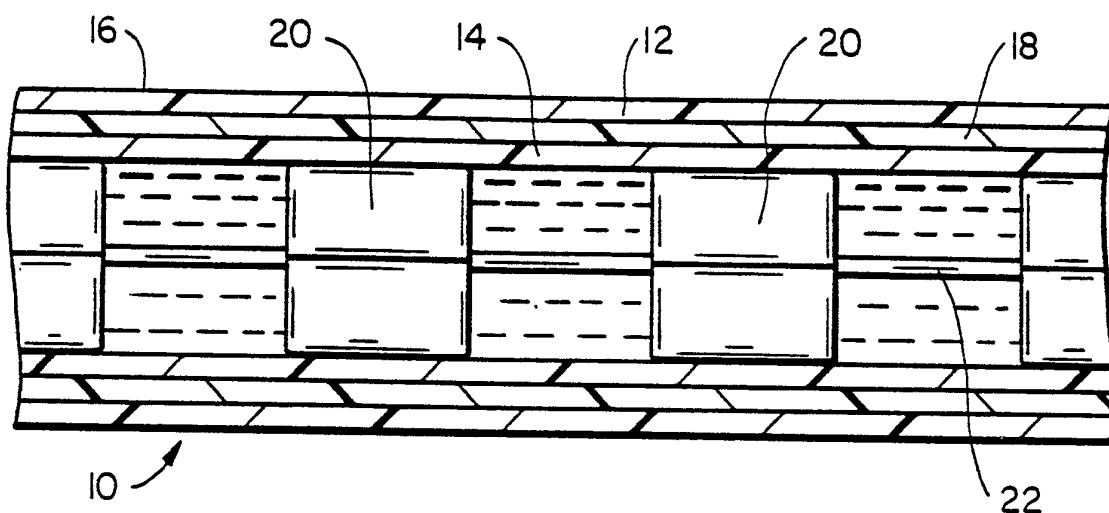


FIG_2

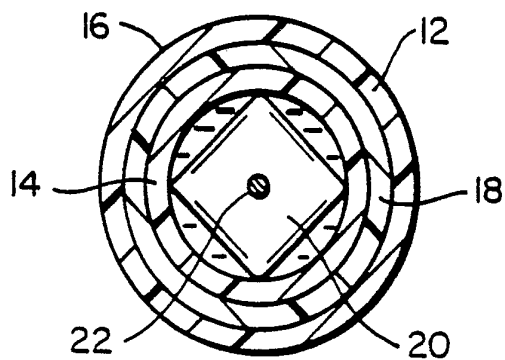


FIG_3

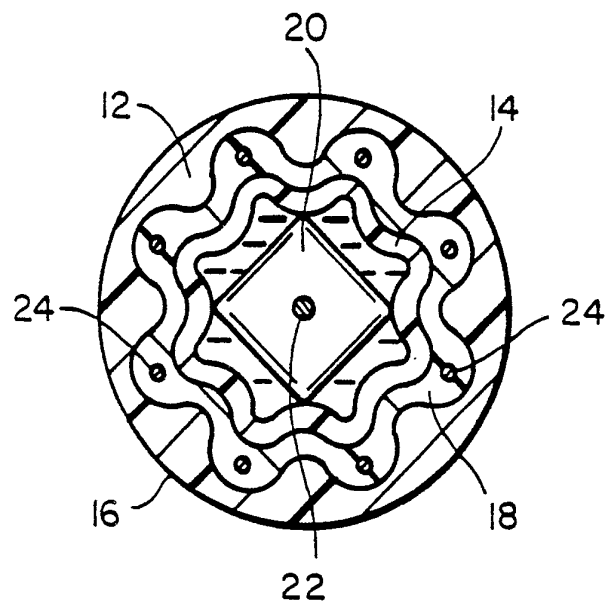


FIG_4

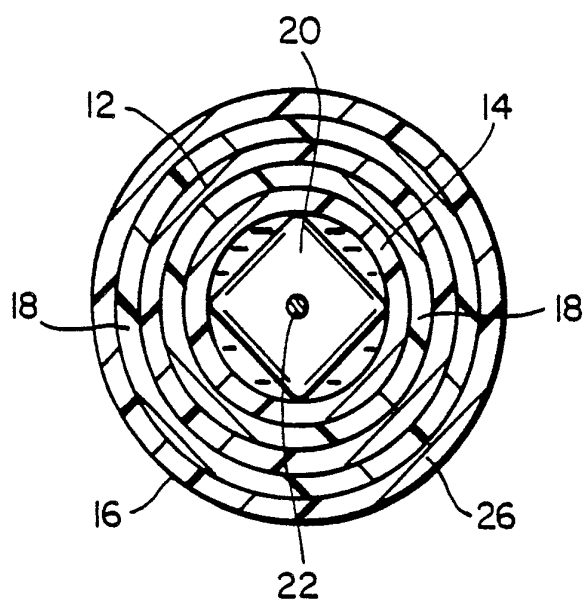
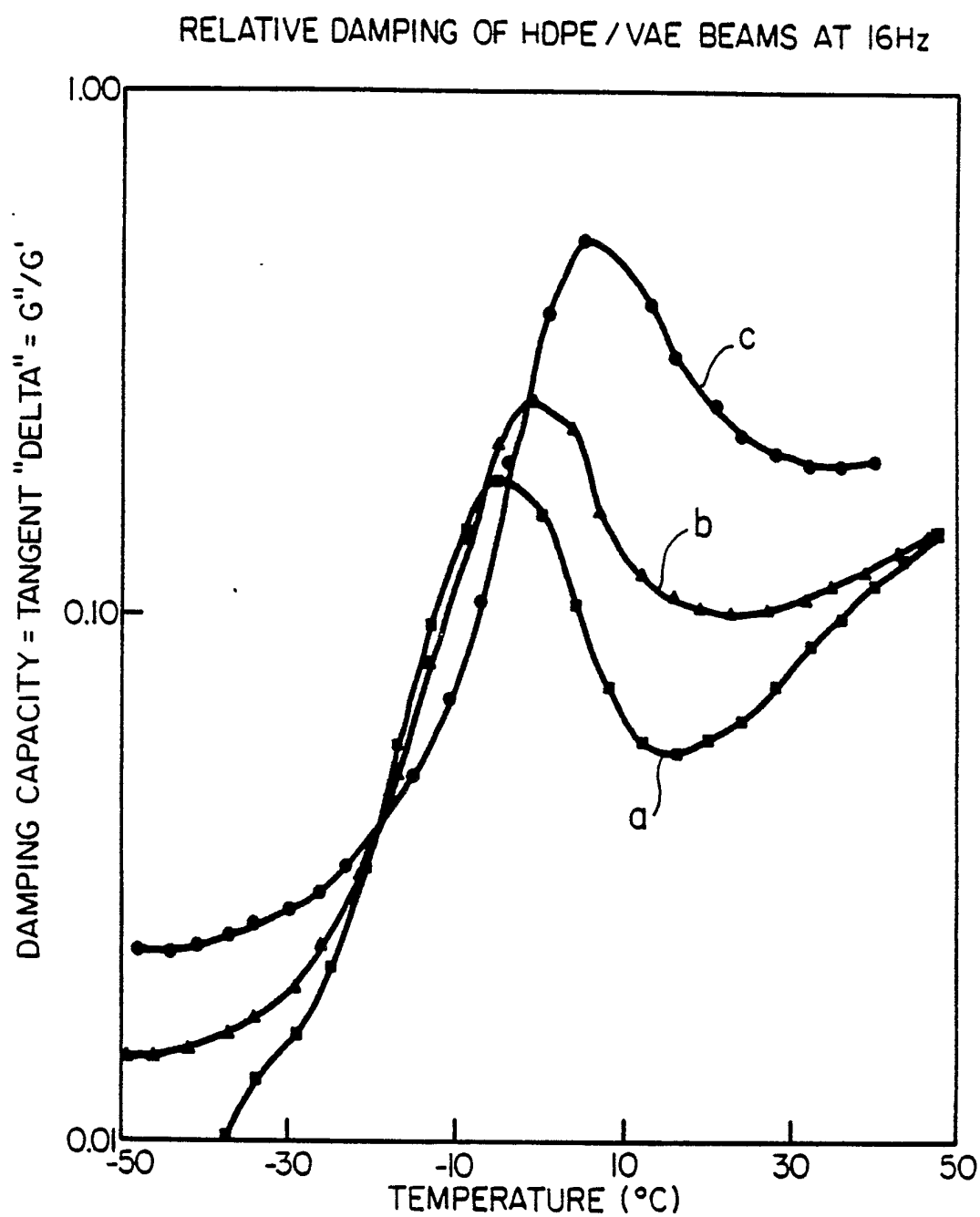


FIG_5

**FIG_6****SUBSTITUTE SHEET**

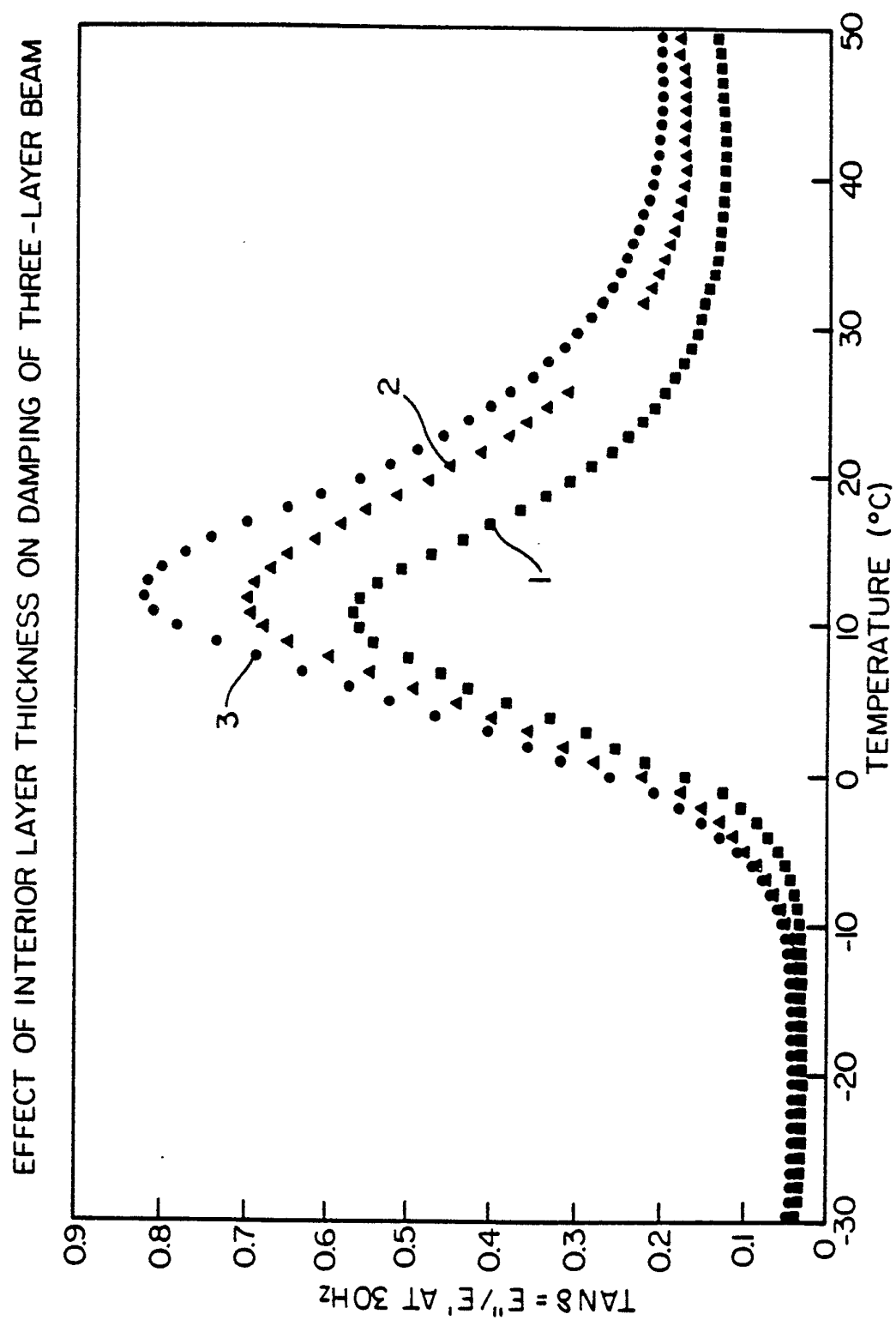


FIG_7

SUBSTITUTE SHEET

INTERNATIONAL SEARCH REPORT

International Application No PCT/US86/02562

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ³		
According to International Patent Classification (IPC) or to both National Classification and IPC		
IPC4 G01V 1/38 US 367/15 174/101.5 138/137		
II. FIELDS SEARCHED		
Minimum Documentation Searched ⁴		
Classification System	Classification Symbols	
U.S.	367/15, 20, 106, 130, 154, 166, 169, 177 181/110 138/137 174/101.5	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched ⁴		
III. DOCUMENTS CONSIDERED TO BE RELEVANT ¹⁴		
Category ⁵	Citation of Document, ¹⁶ with indication, where appropriate, of the relevant passages ¹⁷	Relevant to Claim No. ¹⁸
A	US,A, 3,710,006 (Davis) 9 January, 1973 see entire document	1-10
A	US,A, 3,729,919 (Weichardt et al.) 1 May, 1973 see entire document	1-8, 10
A	US,A, 3,744,016 (Davis) 3 July, 1973 see entire document	1-10
A	US,A, 4,035,534 (Nyberg) 12 July, 1977 see entire document	3
A	US,A, 4,004,187 (Kremkau) 23 August, 1977 see entire document	6
A	US,A, 4,402,069 (Miller et al.) 30 August, 1983 see entire document	1-10
¹⁵ Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. "&" document member of the same patent family		
IV. CERTIFICATION		
Date of the Actual Completion of the International Search ¹	Date of Mailing of this International Search Report ²	
13 January 1987	05 FEB 1987	
International Searching Authority ¹	Signature of Authorized Officer ¹⁹	
ISA/US	John W. Eldred	
	01-28-87	