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(71) Applicant: UNIVERSITY OF ALABAMA AT BIRMINGHAM [US/US]; The Research Foundation, The University of Alabama at Birmingham, Mortimer Jordan Hall, #113, UAB Station, Birmingham, AL 35294-20102 (US).

(72) Inventors: DURBIN, Steven, L. ; 5701 East Shirley Lane, Apt. #1107, Montgomery, AL 36117 (US). WRIGHT, Terry ; 3733 Wimbleton Drive, Birmingham, AL 35223 (US).

(74) Agent: HENDRICKS, Glenna; 9669-A Main Street, P.O. Box 2509, Fairfax, VA 22031-2509 (US).

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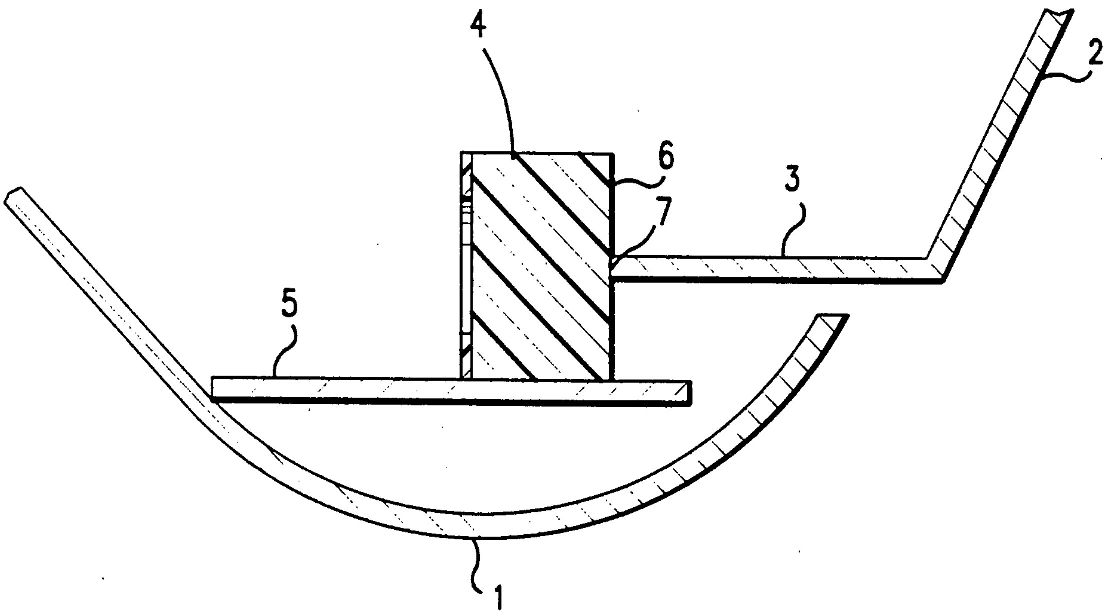


**(57) Abstract**

This invention provides a means of sealing the inner radial surface (7) of a sideplate flange (3) using a stator seal (6) having a face of abradable material (21). Such abradable materials include, but are not limited to, low-density ceramic materials such as fire brick, polymeric material in the form of foam (open or closed cell) or mesh, or metal honeycomb. The sealing devices of the invention minimize effects of a radial inlet clearance gap and are useful in a wide range of centrifugal fans, including large industrial fans.

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# INLET CLEARANCE GAP SEAL

**Field of the Invention:**

This invention relates to devices that eliminate or reduce inefficiency and performance losses which result from leakage flow due to radial inlet clearance gaps in centrifugal fans.

**Background of the Invention:**

The design of air-moving equipment, as with any machinery, is dictated not only by performance parameters, but also by economic considerations. Increased manufacturing costs associated with higher degrees of complexity, tighter tolerances, and more exotic materials must be weighted against the potential benefits to be gained from other factors such as increased energy efficiency.

The design of high-performance centrifugal fans after World War II incorporated several concepts, such as backwardly-curved blades, airfoil blade cross-sections and application of inviscid flow theory to the design of flow passages. Efficiencies of 90% and better have become common while increased specific speeds have made it possible to reduce size while obtaining the same output. Concern for the initial cost has also led to design compromises such as backwardly inclined blades and conical inlet cones and sideplates. Although less efficient than backwardly curved or airfoil blades and aerodynamically streamlined flow passages, these compromise designs have also been easier and cheaper to manufacture. An example of a feature subject to the initial cost/efficiency considerations is the inlet clearance gap, the radial clearance between the fixed inlet cone and the rotating impeller side-plate.

It has been recognized that excessive clearance (increased clearance gap) degrades fan efficiency and performance, but that closing tolerances to reduce radial clearance presents higher manufacturing and installation costs. Hence, it has been the custom to manufacture fans with a clearance gap sufficiently tight to avoid performance degradation, but large enough that special care and expense in manufacture and installation would be avoided.

It has been argued that excessive radial inlet clearance causes unacceptable performance and efficiency losses (Wright, T., "Centrifugal Fan Performance with Inlet Clearance, ASME Paper No. 84-GT-186).

The instant invention is exemplified using metal honeycomb in an abradable seal. An example of a metal honeycomb is disclosed in U.S. Patent 4,346,904. That disclosure is incorporated herein by reference in its entirety. Metal honeycomb has been employed successfully for years for abradable tip seals in aircraft engine turbines and compressors. Metal honeycomb has also been used in power plant gas turbines and shaft seals.

U.S. Patent 5,088,886 teaches a centrifugal fan having a grate of intersecting strips of metal. The device is used to promote uniform air flow from the inlet to the fan.

U.S. Patent 3,627,440 teaches a centrifugal fan having a seal positioned between the inlet cone and the side plate. The seal is not configured to use the edge of the sideplate flange as a rotor.

U.S. Patent 4,767,267 teaches a honeycomb abradable annular seal member. The seal is not configured in a manner that would render it appropriate for use as an inlet gap seal.

**Summary of the Invention:**

It is the purpose of this invention to provide a reliable and cost effective seal that would eliminate or reduce efficiency and performance losses in centrifugal fans which result from leakage flow due to the radial inlet clearance gap. The devices of the invention are stator seals having an abradable face wherein the edge of the sideplate flange functions as a rotor. A retrofittable inlet gap seal comprises a mounting ring having mounted thereon a sealing component, wherein the face of the sealing component is composed of an abradable material. In most instances the sealing portion is affixed to the mounting ring so that the face of the sealing component is generally perpendicular to the flange of the sideplate. It is essential that the inlet gap seal be constructed so that the sealing component having a face composed of an abradable material is positioned so that the end of the sideplate flange (or any extension thereto) interfaces with the face of the seal.

A preferred material for the face is honeycomb metal. More particularly, the preferred embodiment of the invention provides inlet gap seals comprising a mounting ring having mounted thereon an abradable sealing portion comprising a channel packed at least in part with an abradable material. Examples of such materials are abradable, porous, low-density ceramics, abradable polymeric material or metal honeycomb wherein the face of the abradable material and the end of the sideplate flange interface. In a preferred embodiment, the channel is a U-channel which contains a spacer behind abradable metal honeycomb. Such seals can be effectively retrofitted in the field at relatively low cost to increase energy efficiency and performance of the fans. The devices of the invention are adaptable to centrifugal fans, pumps, blowers, compressors and other centrifugal turbo machines of differing designs, sizes and uses.

**Brief Description of the Figures:**

**Fig. 1** depicts a honeycomb seal in cross-section.

**Fig. 2** depicts the location across the seal face (A-A) and detail of the seal face and a cross-section of the seal.

**Fig. 3** is an enlarged section view of the seal face.

**Fig. 4** is a cross section showing a U-channel and spacer.

**Fig. 5** shows detail of lap-joint welding tabs at the ends of the U-channels.

**Fig. 6** shows a seal in cross-section wherein the abradable material is a dense polymeric foam attached to a support backing with the support ring fitting in to the inlet cone in a slightly different pattern from that of **Fig. 1**.

**Fig. 7** shows a 3-dimensional view of the seal-sideplate interface showing the rotation of the sideplate, the mounting ring, the channel, and the honeycomb seal face.

**Detailed Description of the Invention:**

This invention provides a means of sealing the inner radial surface of a sideplate flange using a stator seal having a face of abradable material. Such abradable materials include, but are not limited to, materials such as porous, low-density ceramics, polymeric material in the form of foam (open or closed cell) or mesh, or metal honeycomb. Other acceptable materials include low-density porous metallic materials such as some of the products of powder metallurgy which are comprised of metallic particles weakly bonded by sintering. Fibrous ceramic, polymeric, metallic and organic materials such as carbon in such forms as cloth, batting, or rope may be used in some instances. Fibers of such materials may also be formed into densely packed bristles for use at the face of the seal. Other organic materials such as cork may be used. The choice of material will depend on the particular requirements for strength and resistance to heat in any application of the technology.

The sealing devices of the invention minimize the radial inlet clearance gap and are useful in a wide range of centrifugal fans, including large industrial fans such as, for example, those employed as induced draft fans in fossil fuel- fired electric generating plants. In such applications, the sealing devices must be capable of performing at temperatures of 500°F and above in a corrosive environment and at high linear velocities which at the sealing surfaces of such fans can exceed 235 ft/s. In addition, such sealing devices must function for long periods of time with minimal maintenance with a high degree of reliability. Seals of the invention meet these needs, performing reliably at elevated temperatures of around 500°F and above and can be made corrosion resistant. The seals are capable of withstanding adverse forces such as viscous drag and vibration.

It is particularly advantageous that seals of the invention can be easily installed in the field without special tools and without extensive dismantling of the fans or undue delay in operation of the fans. The design avoids need for close radial tolerances which would be necessary if the flange inner surface were employed as a rotor. Because contact surfaces are aligned axially, variations arising from relative radial misalignment of the rotor and stator due to out-of-roundness, radial growth in operation, inlet cone positioning, or seal mounting can be tolerated to a much greater degree and an effective seal can still be made so long as the rotor (sideplate flange edge) is aligned axially with some point on the seal face (the honeycomb surface). Incidental contact of the seal face and rotor due to impeller "wobble" and mounting of the seal in a zero-clearance position would be acceptable, since the abradable honeycomb would be immediately deformed or abraded away on contact. The rotor would essentially create its own minimum necessary clearance and a true minimum gap would be achieved. In addition, the lack of any "critical" tolerances for installing the seal would make installation relatively easy.

Referring to the figures, **Fig. 1** shows a cross-section of a seal of the invention showing the inlet cone (1) and sideplate (2) of the fan with the seal in place against the inlet cone (1) with the seal support (5) and the actual sealing unit (4) having the face of the abradable material (6) resting against the edge (7) of the sideplate flange (3). **Fig. 2(a)** shows the face of the seal portion (10) with a line (13) identifying the cross section of Figures 2(b) and 2(c). **Fig. 2(b)** shows a longitudinal cross section of a honeycomb seal portion (11) while **Fig. 2(c)** depicts the surface (12) that interfaces with the sideplate flange. **Fig. 3** shows a detail of a part of the face of the honeycomb (21) with a part of the U-channel (20). **Fig. 4** shows a longitudinal cross-section of the seal of example 1 wherein the U-channel (20) which, in the examples supports the honeycomb (23) with a spacer (24) to position the abradable material.

**Fig. 5** depicts one method of connecting support sections of the seal, wherein lap-joint welding tabs at the ends of support sections, the end of one section of the support material panel has a male portion (30) while the end of the second section of the panel has a complementary female tab (30) for joining the seal sections.

**Fig. 6** depicts an alternative seal wherein the seal (44) is composed of a flat ring (47) having attached thereto a polymeric material (46) and wherein the support ring (45) rests within the support cone (1).

**Fig. 7** shows the sideplate flange (51) and identifies the direction of rotation of the sideplate (52). The mounting ring (53) is shown having attached thereto the outer casing of the channel (20) and the spacer (24). The face of the honeycomb (21) and a side view of the honeycomb (23) within the channel can be seen.

**Example 1:**

A seal was designed to fit a fan having the following parameters:

| | | |
|---|---|---|
| Q | 500,000 cfm | 8333.3 ft/s |
| ΔP | 25 InWG | 130.1 $lbf/ft^2$ |
| $\eta$ | 90% | .9 |
| P | 2190 hp | 1,204,500 ft-lbf/s |
| N | 900 rpm | 94.248 $s^{-1}$ |
| D | 119 in | 9.927 ft |
| d | 68 in | 5.65 ft |
| $\sigma$ (482°) | | .00131 $slugs/ft^3$ |

**Fig. 2** shows the assembled seal with selected details to show orientation of the components. The seal has an outside diameter of 69 inches, and inside diameter of 67 inches to optimally seal a diameter of 68 inches. The 1 inch face width is selected to provide a generous tolerance for radial misalignment of stator and rotor as previously discussed. The 3/4 inch depth is selected to provide axial

stability, strength, and rigidity while maintaining geometric simplicity.

The seal is constructed of Hastalloy-x metal honeycomb with a cell width of 1/32 inch (inside dimension), cell depth of 3/32 inch, and foil thickness of .0014 inch. The .0014 inch foil thickness is selected for abradability at the small cell size.

The seal is prefabricated in four segments, both to facilitate installation in the close confines of a fan housing and because most honeycomb manufacturers do not have brazing oven capacity to accommodate large diameter rings. The segment is, therefore, assembled by bending the honeycomb into a U-shaped quarter-circle channel of .031 inch Hastalloy-x. A spacer, a U-shaped quarter circle channel of .031 inch Hastalloy-x is inverted in the larger channel as a base for the honeycomb to maintain it in proper position. Assembly of the segment is completed by oven brazing using an 82% gold, 18% nickel alloy assembled in sheets with the components. The gold-nickel alloy, appropriate for use at temperatures to 1500°F, is chosen because of its good corrosion and oxidation resistance and to avoid thin foil erosion problems associated with nickel-based braze alloys. The face and cross-section details of the seal are shown in **Fig. 3** and **Fig. 4**. Lap-joint welding tabs (**Fig 5**) located at the ends of each segment, top and back, are provided for assembly, each segment having a male and female tab at the clockwise and counterclockwise end, respectively. (**Fig. 1** shows the tabs in cross-section.) A

3/32 inch x 2 inch one-piece Hastalloy-x mounting ring, split to allow it to slip over the small end of the inlet cone, completes the seal assembly.

The cell dimensions are selected based on Ha's study of honeycomb friction factor (Ha, Tae Woong, "Friction Factor Data for Flat Plate Tests of Smooth and Honeycomb Surfaces," Texas A&M University Dept. of Mechanical Engineering, Paper No. TL-SEAL-1-89). His results were preliminary and incomplete, but his data indicated a strong friction factor dependence on cell width-to-depth ratio, with an optimum value of roughly 3:1, which is the cell width-to-depth ratio selected. The 1/32 inch cell size consistently performed better than both larger or smaller cell sizes.

Installation occurs in three stages. The first stage includes dressing of the sideplate flange edge to remove burrs and smooth weld seams and other high spots. The second stage involves installation of the mounting ring on the inlet cone. This requires removal of some duct work and backing from the inlet cone far enough to allow the ring to be slipped over the small end of the cone. After repositioning the inlet cone, flexible spacers are employed to axially and radially position the mounting ring outer surface with respect to the sideplate flange inner surface to assure that the two surfaces are concentric and parallel. The mounting ring could then be tack-welded into place, the spacers removed, and the welding completed. The final stage is installation of the seal. The segments are assembled on the mounting ring and the weld tabs on all but one location clamped and welded. The final joint is welded after the seal has been positioned. The installation, after placement, is completed by tack welding the seal to the mounting ring and sealing all gaps through which leakage could occur. Sealant used in this instance is GE RTV 104 high temperature silicone sealant. However, equivalent sealants known in the art can be used.

Hastalloy-x is chosen as the seal material for this particular application primarily for its superior corrosion resistance, high temperature oxidation resistance and excellent mechanical properties. Because it is readily available as a high quality foil in a variety of foil thicknesses and at relatively low cost, most honeycomb manufacturers could readily supply such honeycomb. The Hastalloy-x is easily brazed or welded using a variety of alloys and techniques. The properties of Hastalloy-x have been described by Wittenauer and Norris ("Structural Honeycomb materials for Advanced Aerospace Designs," Journal of Metals, March, 1990, pp 36-41.)

While the example above delineates use of a preferred material for use as an abradant, one of ordinary skill in the art would readily realize that any abradant which has necessary wearing properties and can withstand high temperatures and corrosive influences could be used in the method of the invention. In less severe applications a broader range of materials as previously described could be employed. According to the preferred use of metal honeycomb as an abradant, other metals could be used, such as those disclosed in U.S. Patent 4,346,904. The honeycomb could also be made of other metals such as copper and aluminum alloys, nickel alloys, most stainless steels and, if corrosion is not a problem, carbon steel. Any material that may be made into a foil can be used to make the honeycomb.

The support for the abradant portion need not be a U-channel, but can be any support which will hold the abradant in position. In the instant example, the U-channel was used as a means of holding the bent honeycomb in place in the preferred position. A channel which will support the honeycomb in the desired configuration is particularly useful in providing strong seals that will function well under conditions of great stress.

**Example 2:**

A seal is made for a fan as described in example 1, except that the abradable material is porous aluminum oxide ceramic placed on a support of steel which is not a U-channel, but wherein the sides of the channel are perpendicular to the back of the channel forming a 90° angle at the juncture between the sides and back of the channel.

The use of the device such as those exemplified provide considerable economic value in energy efficiency. The fan fitted with a seal as disclosed is typical of fans used for induced draft in large fossil fuel power generating plants. The 2190 hp motor operating at 90% efficiency would consume 15,895,341 kilowatt hours of electricity per year (assuming continuous operation for 365 days). If the efficiency of the fan is improved to 92% by inlet clearance seals, the power consumed would be reduced to 15,549,790 kWh, a reduction of 345,551 kWh. In 1990 the Southern Companies reported a fuel cost for coal of 1.94 cents per net kWh generated. Assuming this to be a typical cost, potential first year fuel cost savings of $6700 would be realized. The cost of each seal produced plus cost of labor to install is approximately $1200 or $2400 for the two seals required. Assuming no increase in fuel cost over a 20 year life for the seals, the total savings could amount to $130,000 in fuel costs alone.

The seals of the invention offer several design advantages. The seals avoid introducing dangerous vibration in the fan during operation. It was possible, using the seals, to avoid modification of the fan impeller. Furthermore, honeycomb seals act as damper seals. The seals as designed provide strength and secure mounting means to prevent failure.

It is understood that the particular material used will depend on the environment in which the seal is to be used. If the environment does not present extreme temperatures or exposure to corrosive agents, the materials need not be chosen for their heat and corrosion resistance.

While a seal made in sections has been exemplified, it is possible to make the seal in a one piece unit. Again, the conditions under which the seal will be installed will determine how the seal is made. When seals of the invention are manufactured as part of a new centrifugal device, the manner in which the seal is made will be determined by considerations related to cost and efficiency. The method of jointing parts of the seal may also vary. Parts may be joined by simple but welds or by providing overlapping parts to be welded in the final construction or placement of the seals.

**Claims:**

1. A centrifugal fan having an inlet gap seal wherein the sealing component has a face composed of an abradable material and wherein the edge of said sideplate flange interfaces with said face of said sealing component.

2. A fan of claim 1 wherein the inlet gap seal comprises a mounting ring having the sealing component mounted thereon, said sealing component comprising a support having affixed thereto an abradable material.

3. A fan of claim 1 wherein the sealing component comprises a channel packed at least in part with metal honeycomb.

4. A fan of claim 2 wherein the channel is a U-channel.

5. A seal of claim 3 wherein the U-channel contains a spacer between the back of the U-channel and the honeycomb.

6. A fan of claim 1 containing a seal wherein the mounting ring rests on the inlet cone and wherein the abradable face of the seal rests against the edge of the sideplate flange which acts as the rotor.

7. An inlet gap seal comprising a mounting ring having

mounted thereon a sealing component, said sealing component having a face composed of an abradable material on a support.

**8.** A seal of claim 7 wherein the support is a channel.

**9.** A seal of claim 8 wherein the channel is a U channel.

**10.** A seal of claim 8 wherein the sealing component comprises a channel packed at least in part with metal honeycomb.

**11.** A seal of claim 10 wherein the channel is a U-channel.

**12.** A seal of claim 9 wherein the U-channel contains a spacer between the back of the U-channel and the abradable material.

**13.** A seal of claim 10 wherein the metal honeycomb is made of Hastalloy-x metal.

**14.** A seal of claim 7 wherein the seal is constructed in segments fastened together to form said seal.

**15.** A seal of claim 14 wherein the joints have been secured by brazing with a gold/nickel alloy.

**16.** A seal of claim 8 wherein the support is a channel packed at least in part with an abradable material, and wherein the segments are joined by lap-joint welding tabs.

**17.** A fan of claim 1 wherein the abradable sealing portion comprises a channel packed at least in part with an abradable material.

**18.** A seal of claim 8 wherein the channel contains a spacer between the back of the channel and the abradable material.

**19.** A seal of claim 7 wherein the abradable material is a porous, low-density ceramic material.

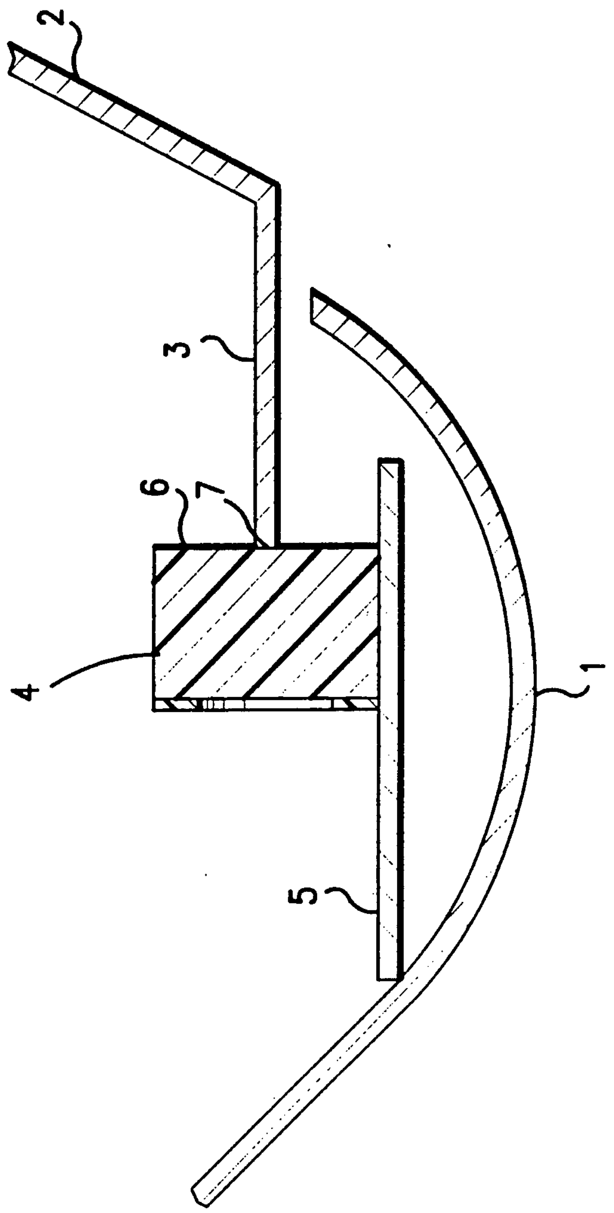


FIG.1

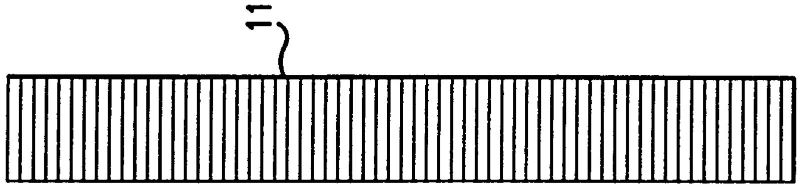


FIG.2b

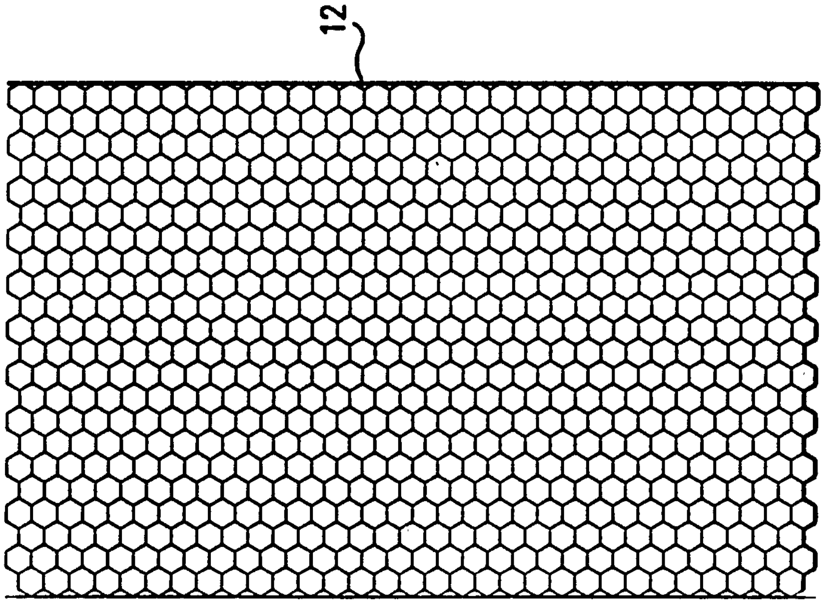


FIG.2c

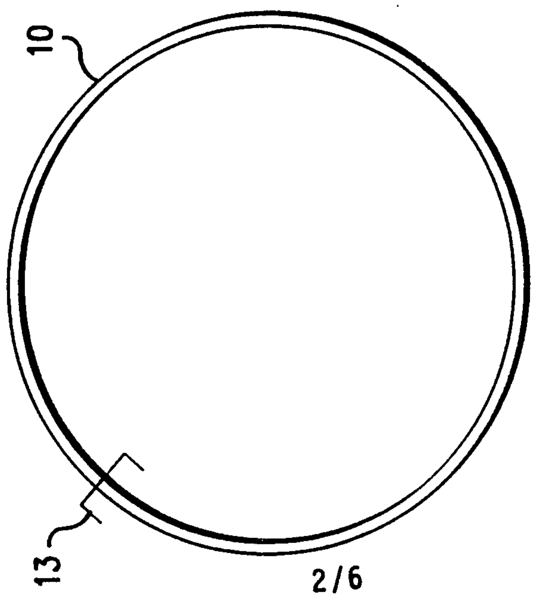


FIG.2a

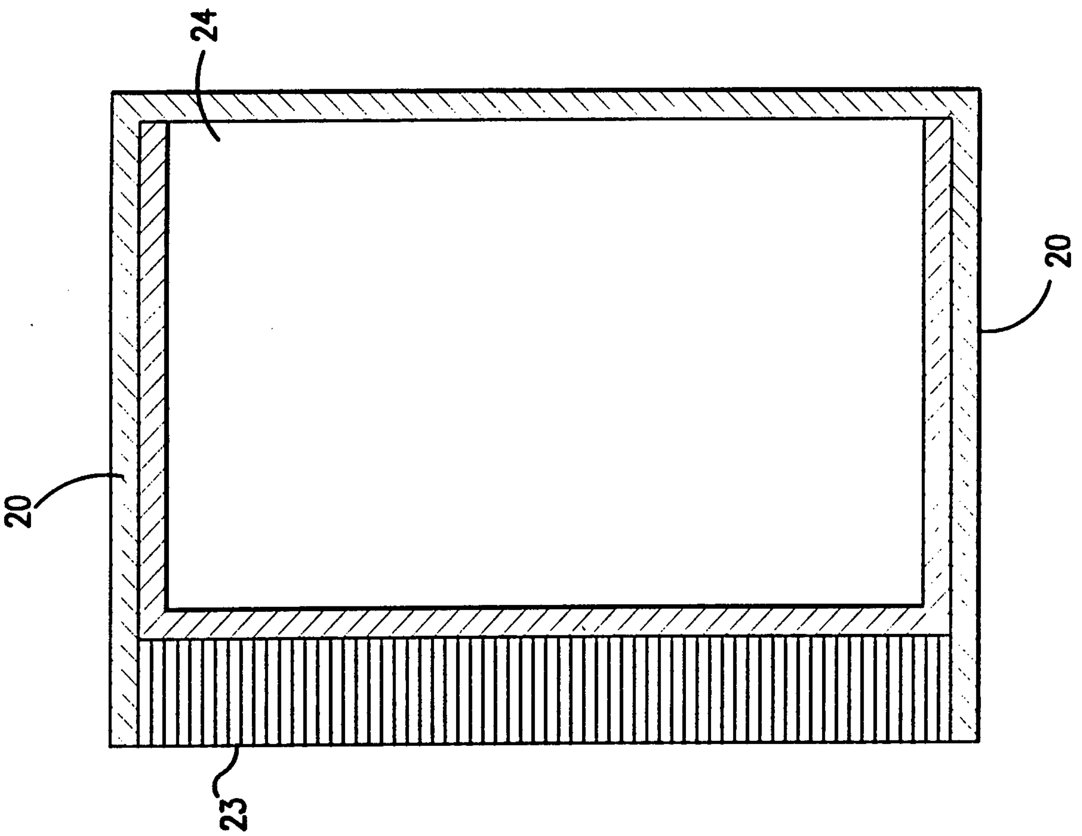


FIG.4

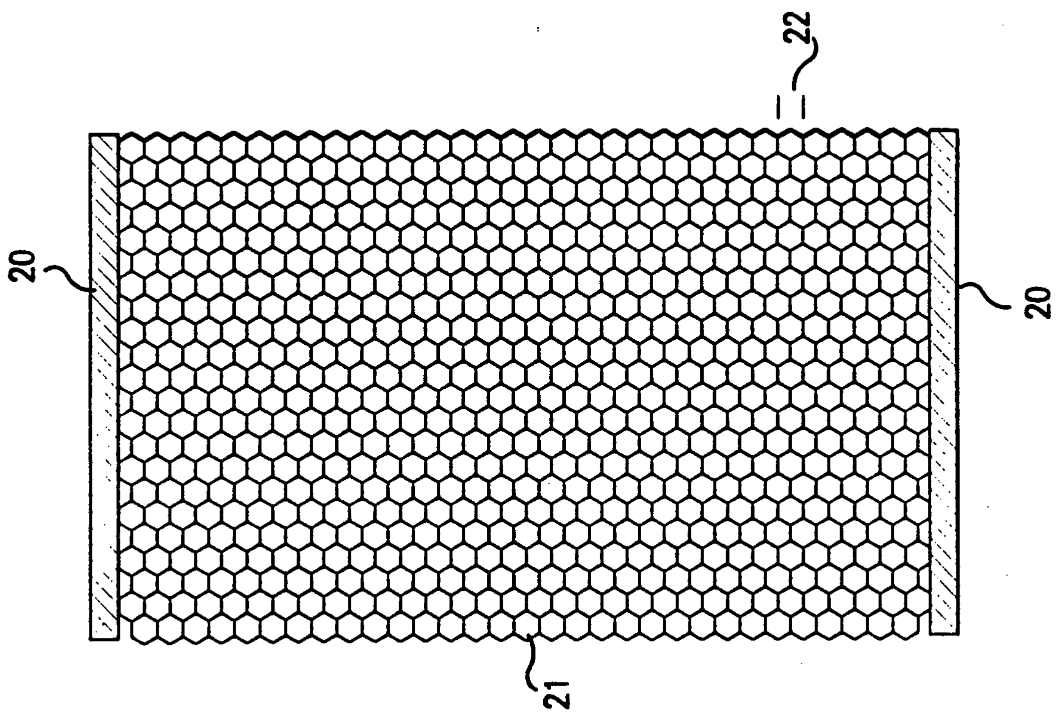


FIG.3

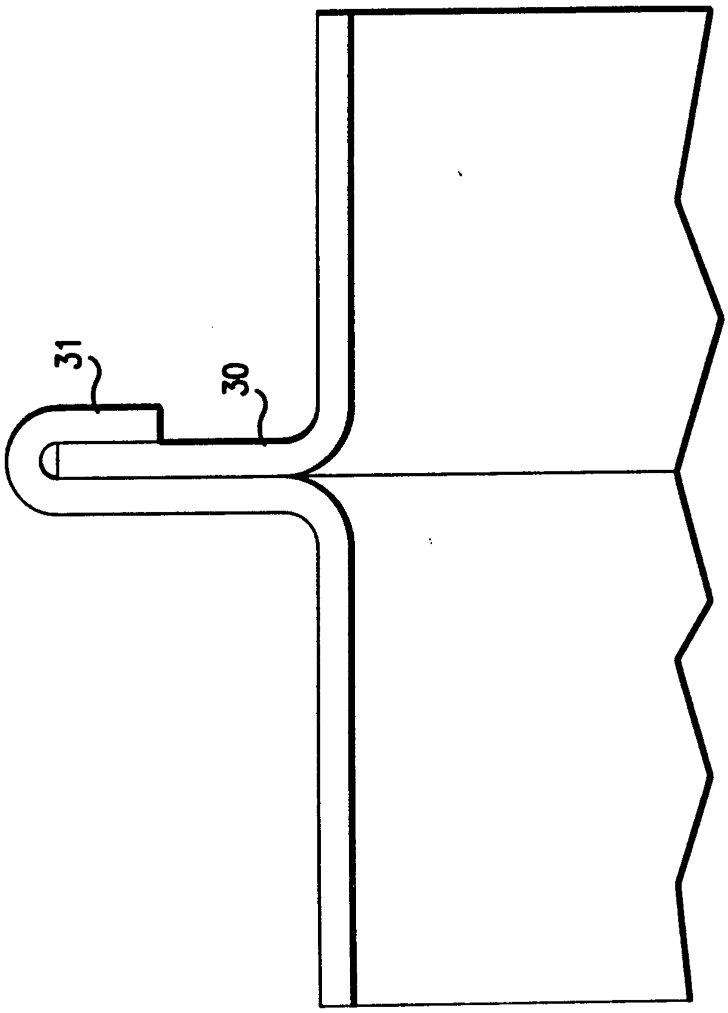


FIG.5

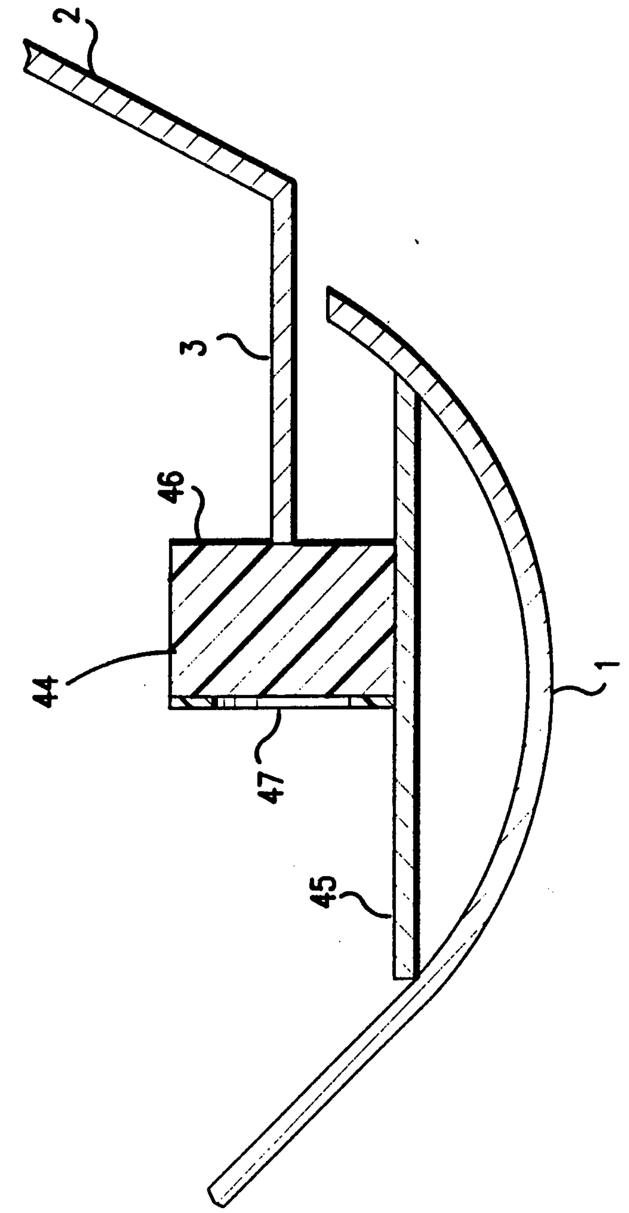


FIG.6

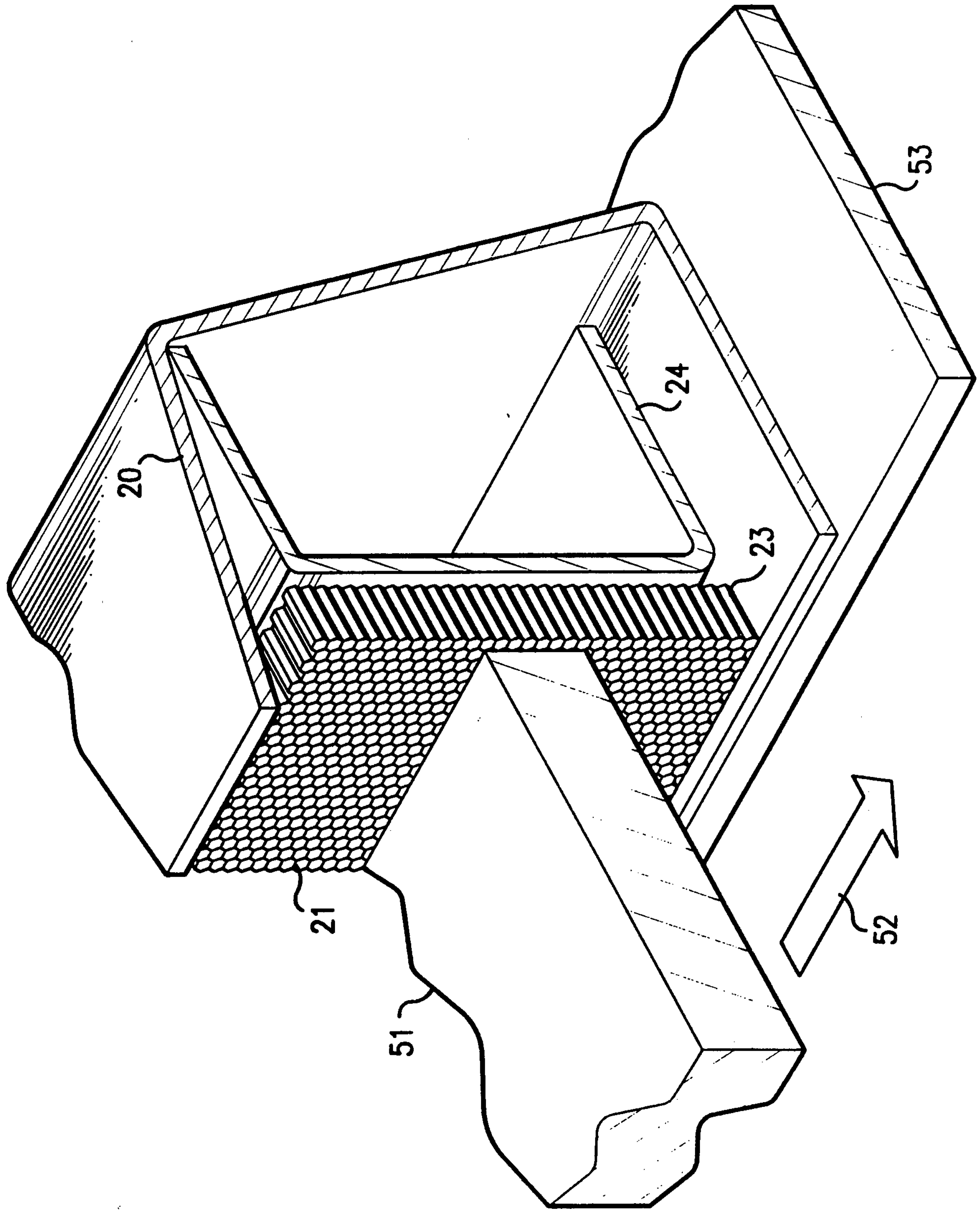


FIG.7

# INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/09447

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(5) :F04D 29/08
US CL : 415/170.1
According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 415/170.1, 172.1, 173.4, 173.5, 173.6, 174.4, 174.5, 173.1; 277/38, 81S, 96, 96.1, 96.2

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

None

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

None

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X<br>------<br>Y | JP, A, 60-212,694 (Sumiya) 24 October 1985, Figures 2 and 4-6. | 1<br>------<br>2-6, 17 |
| P, X | US, A, 5,186,473 (Windges et al) 16 February 1993, Figure 3 and col. 3, lines 1-29. | 5, 7-9, 11-12, 18 |
| X<br>------<br>Y | US, A, 4,767,267 (Salt et al) 30 August 1988, Figures 3-5 and col. 4, lines 38-68, col. 5, lines 1-68, and col. 6, lines 1-39. | 7-9, 16<br>------<br>2, 4, 10, 11, 13-15, 19 |
| Y | US, A, 5,096,376 (Mason et al) 17 March 1992, Figure 5 and col. 6, lines 41-44. | 3, 5, 10, 11, 13-15, 17 |

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 15 November 1993 | 20 DEC 1993 |

| Name and mailing address of the ISA/US | Authorized officer |
|---|---|
| Commissioner of Patents and Trademarks<br>Box PCT<br>Washington, D.C. 20231 | Edward K. Look *Edward K Look* |
| Facsimile No. NOT APPLICABLE | Telephone No. (703) 308-1044 |

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/09447

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| Y | US, A, 3,627,440 (Wood) 14 December 1971, Figure 1. | 6 |
| Y | US, A, 3,918,925 (McComas) 11 November 1975, col. 1, lines 55-57 | 15 |
| Y | US, A, 5,064,727 (Naik et al) 12 November 1991, Abstract, lines 8-14. | 19 |
| A | US, A, 3,656,862 (Rahaim et al) 18 April 1972, Figure 3. | 14 |
| A | US, A, 3,042,365 (Curtis et al) 03 July 1962, Figure 2. | 14 |
| A | US, A, 3,601,182 (Rao) 24 August 1971, Figure 4. | 14 |