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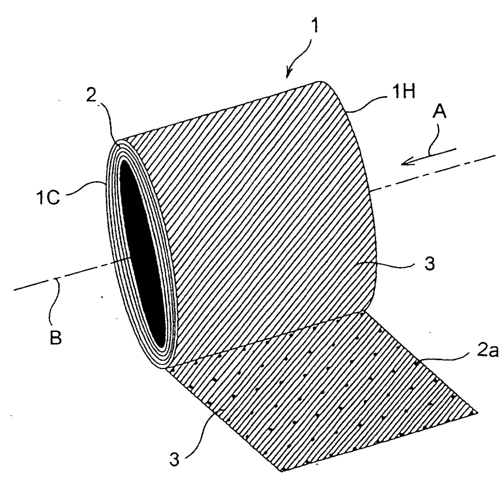
(54) **REGENERATOR, AND HEAT REGENERATIVE SYSTEM FOR FLUIDIZED GAS USING THE REGENERATOR**

(57) In a regenerator 1, on the surface of a strip-shaped resin film 2, a resin layer 3 containing an ingredient having higher thermal conductivity than the resin film 2 is formed; or, over a predetermined width from an edge of the regenerator 1, a resin coating 4 is formed. Then, the resin film 2 is rolled into a cylindrical shape to produce the cylindrical regenerator 1. In a flow gas heat regeneration system having the regenerator 1 disposed in a doughnut-shaped space, when a hot working gas flows into the regenerator 1 through one end thereof, the heat of the working gas is stored in the resin film 2. Here, the resin layer 3 or resin coating 4 on the resin film 2 enhances heat conduction in the regenerator. Thus, more heat is stored in the resin film 2. When the cold working gas flows into the regenerator I through the other end thereof, the heat stored in the resin film 2 is rejected to the working gas. Here, the resin layer 3 or resin coating 4 on the resin film 2 enhances heat conduction in the regenerator 1 and increases the heat capacity thereof Thus, more heat is rejected to the working gas. In this way, it is possible to achieve high heat energy regeneration efficiency.

FIG.1



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Description

Technical field

[0001] The present invention relates to a regenerator for use in a Stirling-cycle refrigerator or the like, and relates also to a flow gas heat regeneration system employing such a regenerator.

Background art

[0002] A type of conventional regenerator 1 for use in a Stirling-cycle refrigerator is, for example as shown in Fig. 8, composed of a resin film 2, having fine projections 2a formed on the surface thereof, rolled into a cylindrical shape with a hollow space left inside it.

[0003] Fig. 9 is a side sectional view of an example of a free-piston-type Stirling-cycle refrigerator incorporating the regenerator 1. First, the operation of this Stirling-cycle refrigerator will be described. As shown in Fig. 9, the free-piston-type Stirling-cycle refrigerator includes a cylinder 8 having a working gas such as helium sealed therein, a displacer 7 and a piston 5 arranged so as to divide the space inside the cylinder 8 into an expansion space 10 and a compression space 9, a linear motor 6 for driving the piston 5 to reciprocate, a heat absorber 14 provided on the expansion space 10 side for absorbing heat from outside, and a heat rejector 13 disposed on the compression space 9 side for rejecting heat to outside.

[0004] In Fig. 9, reference numerals 11 and 12 represent plate springs that support the displacer 7 and the piston 5, respectively, and permit them to reciprocate by resilience Reference numeral 15 represents a heat rejecting heat exchanger, and reference numeral 16 represents a heat absorbing heat exchanger. These heat exchangers prompt exchange of heat between inside and outside the refrigerator. Between the heat rejecting heat exchanger 15 and the heat absorbing heat exchanger 16, a regenerator 1 is disposed.

[0005] In this structure, when the linear motor 6 is driven, the piston 5 moves up inside the cylinder 8, compressing the working gas in the compression space 9. As the working gas is compressed, its temperature rises, but simultaneously the working gas is cooled through heat exchange with the outside air by the heat rejector 13 through the heat rejecting heat exchanger 15. Thus, isothermal compression is achieved. The working gas compressed in the compression space 9 by the piston 5 flows, under pressure, into the regenerator 1 and then into the expansion space 10. Meanwhile, the heat of the working gas is stored in the resin film 2 constituting the regenerator 1, and thus the temperature of the working gas falls.

[0006] The working gas that has flowed into the expansion space 10 is under high pressure, and is expanded when the displacer 7, which reciprocates with a predetermined phase difference kept relative to the piston 5, moves down. Meanwhile, the temperature of the working gas falls, but the working gas is heated through absorption of heat from the outside air by the heat absorber 14 through the heat absorbing heat exchanger 16. Thus, isothermal expansion is achieved. Thereafter, the displacer 7 starts moving up, and thus the working gas in the expansion space 10 flows through the regenerator 1 back into the compression space 9. Meanwhile, the working gas receives the heat stored in the regenerator 1, and thus the temperature of the working gas rises. This sequence of operations, called the Stirling cycle, is repeated by the reciprocating movement of the driven components, with the result that the heat absorber 14 absorbs heat from the outside air and gradually becomes cold.

[0007] In this way, the heat energy of the working gas is regenerated by the regenerator 1 between the compression space 9 and the expansion space 10. Here, increasing the amount of heat stored in the regenerator 1 results in higher heat energy regeneration efficiency. This makes it possible to achieve an ideal Stirling cycle and thereby enhance the refrigerating performance of the Stirling-cycle refrigerator.

[0008] However, in the structure of the conventional regenerator 1 described above, the regenerator 1 itself is composed of a resin film 2, which generally has low thermal conductivity. This leads to low heat conduction from the working gas to the resin film 2. Thus, the regenerator 1 cannot store a sufficient amount of heat, resulting in unsatisfactory heat energy regeneration efficiency. This lowers the refrigerating performance of the Stirling-cycle refrigerator. Moreover, the edges of the regenerator are prone to deformation, causing variations in regeneration performance and leading to unstable regeneration performance. Accordingly, an object of the present invention is to provide a regenerator that offers excellent heat energy regeneration efficiency and stable regeneration performance.

Disclosure of the invention

[0009] To achieve the above object, according to one aspect of the present invention, in a regenerator composed of a strip-shaped resin film rolled into a cylindrical shape, the resin film has a multiple layer structure at least in a portion thereof occupying a predetermined width from an edge thereof. This helps increase the strength of the edges of the regenerator so that they are less prone to deformation, and thus helps stabilize the performance of the regenerator.

[0010] According to another aspect of the present invention, in a regenerator composed of a strip-shaped resin film rolled into a cylindrical shape, a layer having higher thermal conductivity than the resin film is formed on the surface of the resin film. When the hot working gas flows into the regenerator through one end thereof, the heat of the working gas is stored in the resin film. Here, the layer having high thermal conductivity formed on the resin film enhances heat conduction in the regenerator. Thus, more heat is stored in the resin film. When the cold working gas flows into the regenerator through the other end thereof, the working gas receives the heat stored in the resin film. Here, the layer having high thermal conductivity formed on the resin film enhances heat conduction in the regenerator 1 and provides higher heat capacity. Thus, more heat is rejected to the working gas. In this way, it is possible to achieve high heat energy regeneration efficiency.

[0011] The resin film may have a plurality of fine projections formed on the surface thereof. This leaves gaps between different turns of the resin film laid on one another, and thus permits the working gas to flow through those gaps from the high-temperature end to the low-temperature end and vice versa along the cylinder axis.

[0012] According to still another aspect of the present invention, in a regenerator composed of a strip-shaped resin film rolled into a cylindrical shape, the resin film is composed of two strip-shaped resin films having a layer with higher thermal conductivity than the two resin films laminated between the two resin films. This helps avoid exposing the layer having high thermal conductivity to outside.

[0013] In particular, forming the layer having high thermal conductivity on the resin film so as to occupy a predetermined with from an edge of the regenerator helps reduce the area, and thus the material costs and the like, of the layer having high thermal conductivity compared with a case where the layer having high thermal conductivity is formed all over the resin film.

[0014] The layer having high thermal conductivity can be formed easily by being printed on the resin film as resin ink containing an ingredient having high thermal conductivity. In that case, suitable as the ingredient having high thermal conductivity is fine particles of at least one of gold, silver, copper, aluminum, and carbon.

[0015] By disposing the regenerator of the present invention in a doughnut-shaped space serving as a flow pass for a reciprocating gas, it is possible to realize a versatile flow gas heat regeneration system that offers high heat energy regeneration efficiency. In particular, by applying the present invention to a free-piston-type Stirling-cycle refrigerator, it is possible to achieve excellent refrigerating performance.

Brief description of drawings

[0016]

Fig. 1 is a perspective view showing the structure of the regenerator of a first embodiment of the invention.

Fig. 2 is an enlarged sectional view of the regenerator.

Fig. 3 is a perspective view showing the structure of the regenerator of a second embodiment of the invention.

Fig. 4 is a perspective view showing the structure of the regenerator of a third embodiment of the invention.

Fig. 5 is a perspective view showing the structure of the regenerator of a fourth embodiment of the invention.

Fig. 6 is a perspective view showing the structure of the regenerator of a fifth embodiment of the invention.

Fig. 7 is an enlarged sectional view showing the regenerator of a sixth embodiment of the invention.

Fig. 8 is a perspective view showing the structure of an example of a conventional regenerator.

Fig. 9 is a side sectional view showing an example of a free-piston-type Stirling-cycle refrigerator.

Best mode for carrying out the invention

[0017] A first embodiment of the invention will be described with reference to the drawings. Fig. 1 is a perspective view showing the structure of the regenerator of the first embodiment of the invention, and Fig. 2 is an enlarged sectional view of the regenerator. As shown in Fig. 1, the regenerator 1 is composed of a strip-shaped resin film 2 rolled into a cylindrical shape. The resin film 2 is formed out of a material having high specific heat, low thermal conductivity, high heat resistance, low moisture absorption, and other desirable properties, suitable examples including polyethylene terephthalate (PET) and polyimide.

[0018] The resin film 2 has a plurality of fine projections 2a formed regularly all over one surface thereof. These projections 2a can be formed, for example, by printing, embossing, or heat forming. As shown in Fig. 2, the projections 2a permit gaps to be left between different turns of the resin film 2 laid on one another. Thus, through these gaps, as shown in Fig. 1, the working gas flows from the high-temperature end 1H to the low-temperature end 1C as indicated by an arrow A and vice versa along the cylinder axis (the direction indicated by a dash-and-dot line B).

[0019] On both surfaces of the resin film 2, resin layers 3 containing an ingredient having higher thermal conductivity than the resin film 2 are formed as thin films. Suitable as the ingredient having high thermal conductivity is fine particles of gold, silver, copper, aluminum, carbon, or the like used singly or as a mixture of two or more of them. The fine particles are mixed with a resin material such as polyethylene, and the mixture is then printed, as ink, on both surfaces of the resin film 2 to coat it with the resin layers 3.

[0020] Next, how heat regeneration is achieved in a Stirling-cycle refrigerator employing this regenerator 1 will be described. When a working gas compressed and thereby heated flows into the regenerator 1 through the high-temperature end 1H thereof, the heat energy of the working gas is stored in the resin film 2. Here, since the resin layers 3 on the resin film 2 have sufficiently high thermal conductivity, the heat energy first conducts along the resin layers 3 and is then stored in the entire resin film 2. Thus, a sufficient amount of heat is stored. On the other hand, when the working gas expanded and thereby cooled flows into the regenerator 1 through the low-temperature end 1C thereof, the stored heat is rejected. Here, the heat energy conducts along the resin layers 3 and is rejected from the entire resin film 2 to the working gas. Thus, a sufficient amount of heat is rejected. In this way, the regenerator 1 operates with enhanced regeneration energy efficiency

[0021] A second embodiment of the invention will be described with reference to the drawings. Fig. 3 is a perspective view showing the structure of the regenerator of the second embodiment of the invention. As shown in Fig. 3, the resin film 2 has a plurality of fine projections 2a formed regularly all over one surface thereof. These projections 2a permit gaps to be left between different turns of the resin film 2 laid on one another. Thus, through these gaps, the working gas flows from the high-temperature end 1H to the low-temperature end 1C as indicated by an arrow A and vice versa along the cylinder axis (the direction indicated by a dash-and-dot line B).

[0022] As shown in Fig. 3, on both surfaces of the resin film 2, resin layers 3 containing an ingredient having higher thermal conductivity than the resin film 2 are formed in the shape of stripes arranged at regular intervals along the cylinder axis. In the portions on the surfaces of the resin film 2 where the resin layers 3 are not formed, masks are laid beforehand in the shape of stripes arranged at regular intervals. Then, coating is performed just as in the first embodiment. Lastly, the masks are washed off and removed to obtain the resin layers 3. The stripes of the resin layers 3 may be arranged at irregular intervals.

[0023] Next, how heat regeneration is achieved in a Stirling-cycle refrigerator employing this regenerator 1 will be described. When a working gas compressed and thereby heated flows into the regenerator 1 through the high-temperature end 1H thereof, the heat energy of the working gas is stored in the resin film 2. Here, since the resin layers 3 on the resin film 2 have sufficiently high thermal conductivity, the heat energy first conducts to the individual stripes of the resin layers 3 and is then stored from the individual stripes to the resin film 2. Thus, a sufficient amount of heat is stored. On the other hand, when the working gas expanded and thereby cooled flows into the regenerator 1 through the low-temperature end 1C thereof, the stored heat is rejected. Here, the heat energy conducts from the resin film 2 to the individual stripes of the resin layers 3 and is then rejected to the working gas. Thus, a sufficient amount of heat is rejected. In this way, the regenerator 1 operates with enhanced regeneration energy efficiency.

[0024] In this embodiment, the resin layers 3 on the resin film 2 are formed in the shape of stripes arranged at intervals. This helps reduce the loss of heat during heat conduction through the resin layers 3 from the high-temperature end 1H to the low-temperature end 1C. Moreover, the resin layers 3 have a smaller area than when they are formed all over the resin film 2. This helps reduce the amount of the high-thermal-conductivity ingredient used, and thus helps reduce costs. Although the portions where the resin layers 3 are not formed have comparatively low thermal conductivity, since the resin layers 3 are formed in the shape of stripes, by determining the widths and intervals of the stripes of the resin layers 3 so that the working gas makes as little contact as possible with those low-thermal-conductivity portions, it is possible to minimize the lowering of heat energy regeneration efficiency.

[0025] A third embodiment of the invention will be described with reference to the drawings. Fig. 4 is a perspective view showing the structure of the regenerator of the third embodiment of the invention. As shown in Fig. 4, the resin film 2 has a plurality of fine projections 2a formed regularly all over one surface thereof. These projections 2a permit gaps to be left between different turns of the resin film 2 laid on one another. Thus, through these gaps, the working gas flows from the high-temperature end 1H to the low-temperature end 1C as indicated by an arrow A and vice versa along the cylinder axis (the direction indicated by a dash-and-dot line B). Here, the portions of the regenerator 1 around the high-temperature end 1H and the low-temperature end 1C thereof contribute to heat energy regeneration to a particularly high degree.

[0026] As shown in Fig. 4, on both surfaces of the resin film 2, resin layers 3 containing an ingredient having higher thermal conductivity than the resin film 2 are formed so as to occupy a predetermined width from each edge of the regenerator 1 by the same process as in the second embodiment.

[0027] In this embodiment, the resin layers 3 on the resin film 2 are formed to occupy a predetermined width from each edge of the regenerator 1, and thus have a smaller area than when they are formed all over. This helps accordingly reduce the amount of the high-thermal-conductivity ingredient used, and thus helps reduce costs. Moreover, since these portions of the regenerator 1 contribute to heat energy regeneration to a high degree, almost no lowering in the performance of the regenerator 1 results.

[0028] A fourth embodiment of the invention will be described with reference to the drawings. Fig. 5 is a perspective view showing the structure of the regenerator of the fourth embodiment of the invention.

[0029] As shown in Fig. 5, on both surfaces of the resin film 2, resin layers 3 containing an ingredient having higher thermal conductivity than the resin film 2 are formed in the shape of stripes arranged at regular intervals along the cylinder axis so as to occupy a predetermined width from each edge of the regenerator 1.

[0030] In this embodiment, the resin layers 3 on the resin film 2 are formed at intervals so as to occupy a predetermined width from each edge of the regenerator 1, and thus have a smaller area than when they are formed all over. This helps accordingly reduce the amount of the high-thermal-conductivity ingredient used, and thus helps reduce costs. Moreover, since these portions of the regenerator 1 contribute to heat energy regeneration to a high degree, almost no lowering in the performance of the regenerator 1 results.

[0031] In the embodiments described thus far, the resin film 2 is described as having the resin layers 3 formed on both surfaces thereof However, it is also possible to form a resin layer only on one surface of the resin film. In that case, less ink is required, and coating needs to be performed only once. This greatly reduces costs.

[0032] A fifth embodiment of the invention will be described with reference to the drawings. Fig. 6 is a perspective view showing the structure of the regenerator of the fifth embodiment of the invention.

[0033] As shown in Fig. 6, on both surfaces of the resin film 2, resin coatings 4 of polyethylene or the like are formed so as to occupy a predetermined width from each edge of the regenerator 1. In the central portions on the surfaces of the resin film 2 where the resin coatings 4 need not be formed, masks are laid beforehand. Then, a resin material is printed as ink on both surfaces of the resin film 2 to achieve coating. Lastly, the masks are washed off and removed to obtain the resin coatings 4.

[0034] In this embodiment, by forming the resin coatings 4, the portions of the resin film 2 occupying a predetermined width from each edge thereof, i.e., the portions that contribute to heat energy regeneration to a high degree, are made thicker. This not only helps increase heat storage capacity and thereby enhance heat energy regeneration efficiency, but also helps make the resin film 2 less prone to develop wrinkles when rolled up.

[0035] In this embodiment, the resin film 2 is described as having the resin coatings 4 formed on both surfaces thereof. However, it is also possible to form a resin coating only on one surface of the resin film. In that case, less ink is required, and coating needs to be performed only once. This greatly reduces costs.

[0036] A sixth embodiment of the invention will be described with reference to the drawings. Fig. 7 is an enlarged sectional view showing the regenerator of the sixth embodiment of the invention. As shown in Fig. 7, the regenerator 1 is composed of a composite resin film 20 rolled into a cylindrical shape. The composite resin film 20 is composed of two strip-shaped resin films 21 and 22 having a resin layer 3, described later, laminated between them. One resin film 21 has a plurality of fine projections 2a formed regularly all over one surface thereof As shown in Fig. 7, these projections 2a permit gaps to be left between different turns of the composite resin film 20 laid on one another. Thus, through these gaps, as shown in Fig. 1, the working gas flows from the high-temperature end 1H to the low-temperature end 1C as indicated by an arrow A and vice versa along the cylinder axis.

[0037] On one surface of the resin film 22, a resin layer 3 having higher thermal conductivity than the resin film 22 is formed as a thin film. The two resin films 21 and 22 are laid together so that the surface of the resin film 22 on which the resin layer 3 is formed is kept in intimate contact with the surface of the resin film 21 on which the projections 2a are not formed. In this way, the composite resin film 20 having the resin layer 3 laminated inside it is produced.

[0038] In this embodiment, the resin layer 3 is not exposed to outside, and therefore it never drops off. This greatly enhances durability In this case, the laminated resin layer 3 may be formed in stripes arranged at predetermined intervals along the cylinder axis as shown in Fig. 3, or may be formed so as to occupy a predetermined width from each edge of the regenerator 1 as shown in Fig. 4, or may be formed in stripes arranged at predetermined intervals along the cylinder axis so as to occupy a predetermined width from each edge of the regenerator 1 as shown in Fig. 5.

[0039] In all the embodiments described above, the resin layer or layers 3 are described as being printed as ink. However, they may be formed by any other method, such as painting, vapor deposition, plating, or application of a thin film tape.

[0040] By disposing a regenerator 1 structured as described above in a doughnut-shaped space to constitute a system in which a gas is made to flow through that space in a reciprocating fashion, it is possible to realize a versatile flow gas heat regeneration system as exemplified by a free-piston-type Stirling-cycle refrigerator.

Industrial applicability

[0041] As described above, according to the present invention, in a regenerator composed of a strip-shaped resin film rolled into a cylindrical shape, on the surface of the resin film, a layer having higher thermal conductivity than the resin film is formed, or alternatively a resin coating is formed so as to occupy a predetermined width from an edge of the regenerator. This increases heat conduction in the regenerator and stabilizes the performance thereof. In a flow gas heat regeneration system having this regenerator disposed in a doughnut-shaped space, when a hot working gas flows into the regenerator through one end thereof, the heat of the working gas is stored in the resin film. Here, the layer having high thermal conductivity or the resin coating formed on the resin film enhances heat conduction in the regenerator. Thus, more heat is stored in the resin film. When the cold working gas flows into the regenerator through the other end thereof, the heat stored in the resin film is rejected to the working gas. Here, the layer having high thermal conductivity or the resin coating formed on the resin film enhances heat conduction in the regenerator and increases the heat capacity thereof

Thus, more heat is rejected to the working gas. In this way, it is possible to achieve high heat energy regeneration efficiency.

[0042] In particular, when the regenerator of the present invention is applied to a free-piston-type Stirling-cycle refrigerator, it is possible to achieve excellent refrigerating performance.

Claims

1. A regenerator composed of a strip-shaped resin film rolled into a cylindrical shape, wherein the resin film has a multiple layer structure at least in a portion thereof occupying a predetermined width from an edge thereof

2. A regenerator as claimed in claim 1, wherein the resin film has a plurality of fine projections formed on a surface thereof.

3. A regenerator as claimed in claim 1, wherein a layer used to form the multiple layer structure has higher thermal conductivity than the resin film.

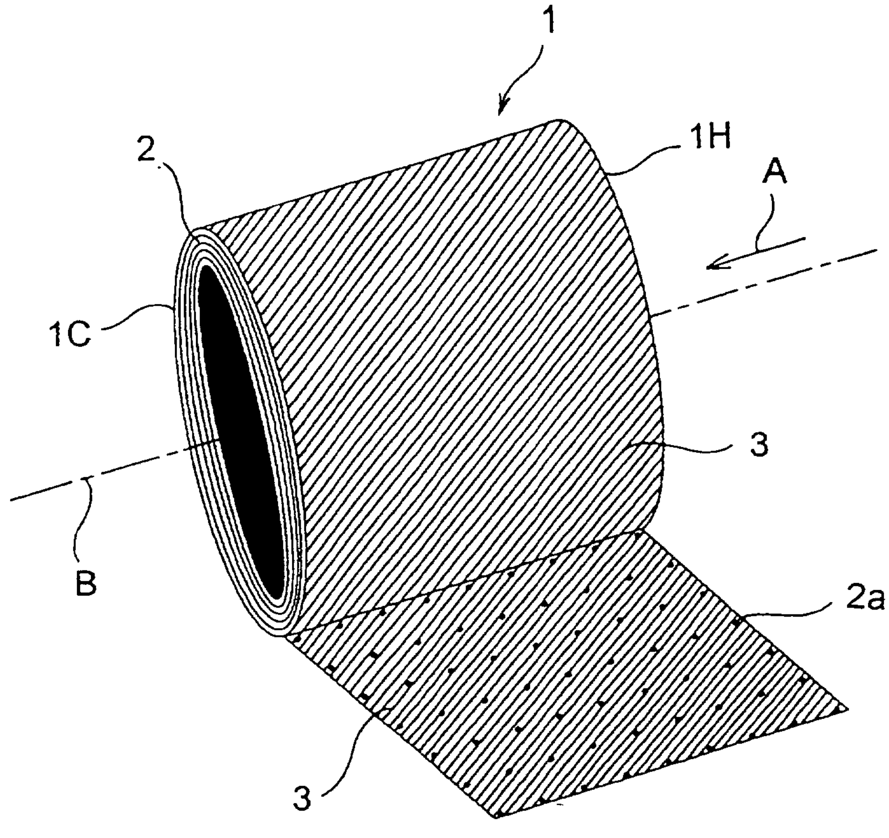
4. A regenerator as claimed in claim 3, wherein the layer having higher thermal conductivity is a resin layer containing an ingredient having high thermal conductivity, and the ingredient having high thermal conductivity is fine particles of at least one of gold, silver, copper, aluminum, and carbon.

5. A regenerator composed of a strip-shaped resin film rolled into a cylindrical shape, wherein a layer having higher thermal conductivity than the resin film is formed on a surface of the resin film.

6. A regenerator composed of a strip-shaped resin film rolled into a cylindrical shape, the resin film being composed of two strip-shaped resin films having a layer with higher thermal conductivity than the two resin films laminated between the two resin films.

7. A flow gas heat regeneration system comprising a regenerator as claimed in one of claims 1 to 6 disposed in a flow path of reciprocating gas.

FIG.1



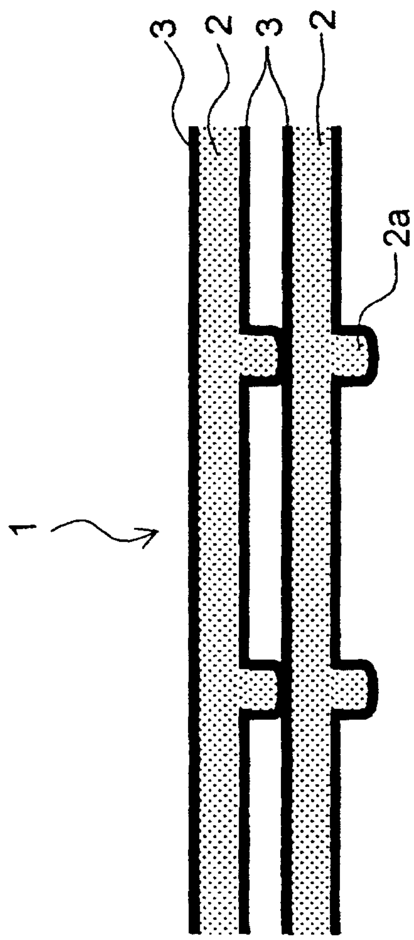


FIG.2

FIG.3

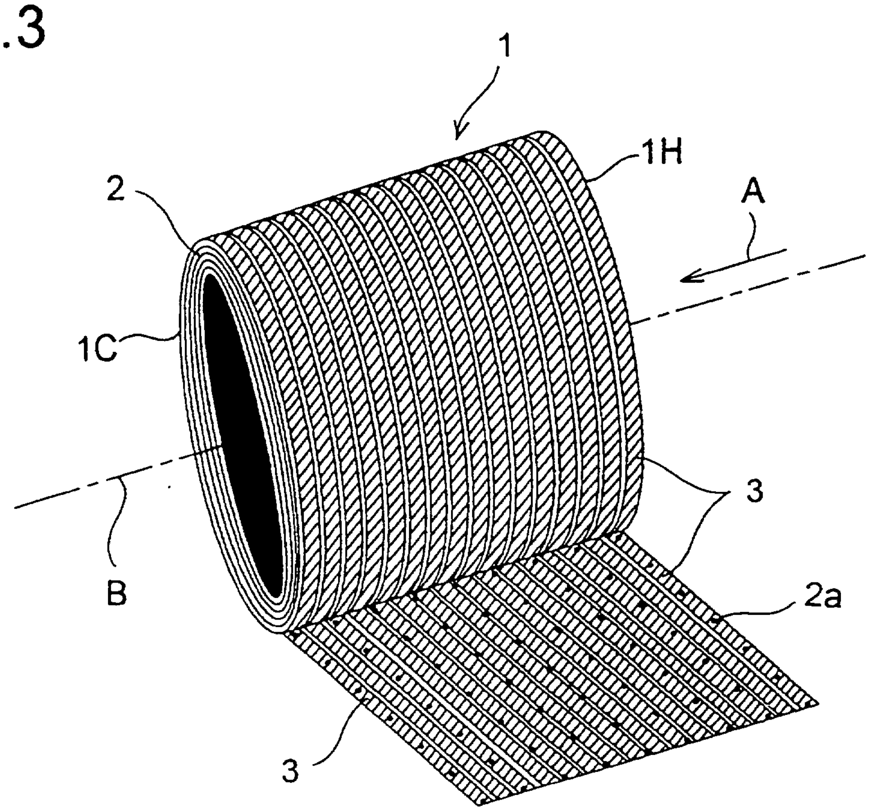


FIG.4

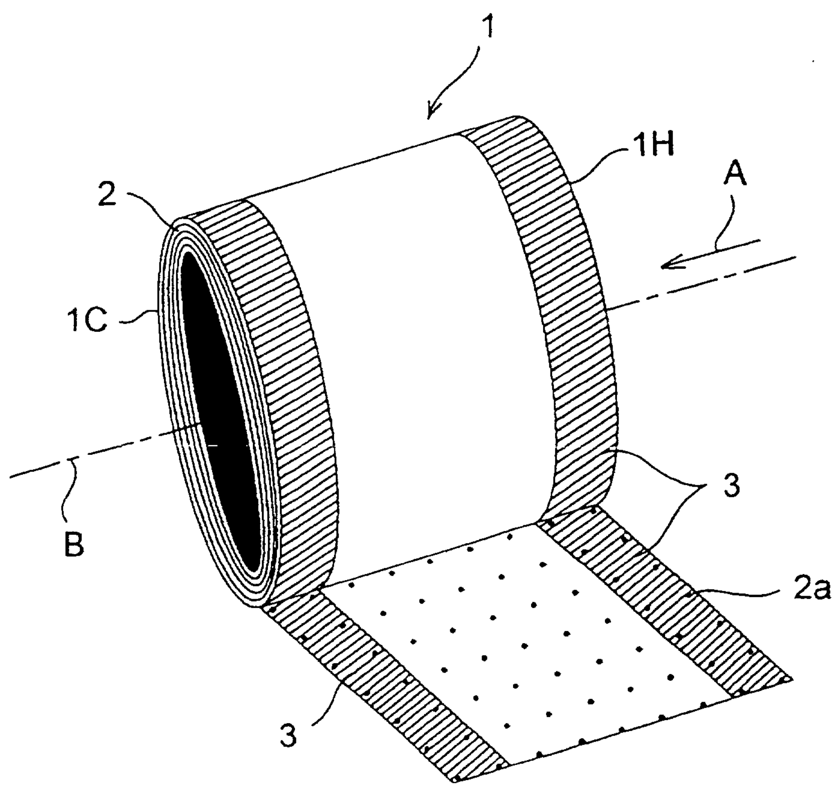


FIG.5

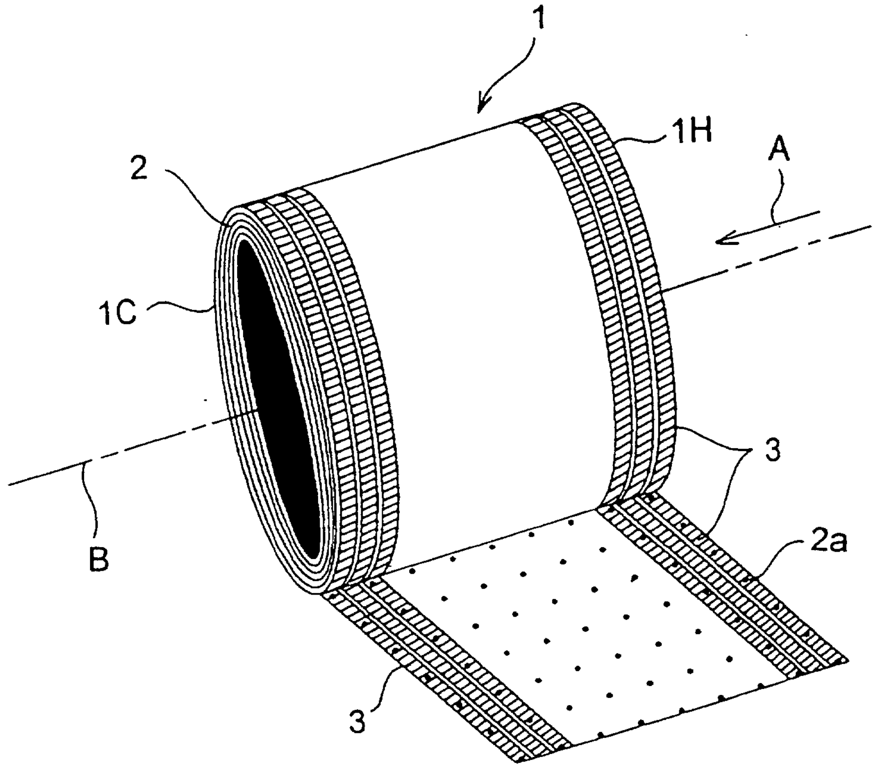
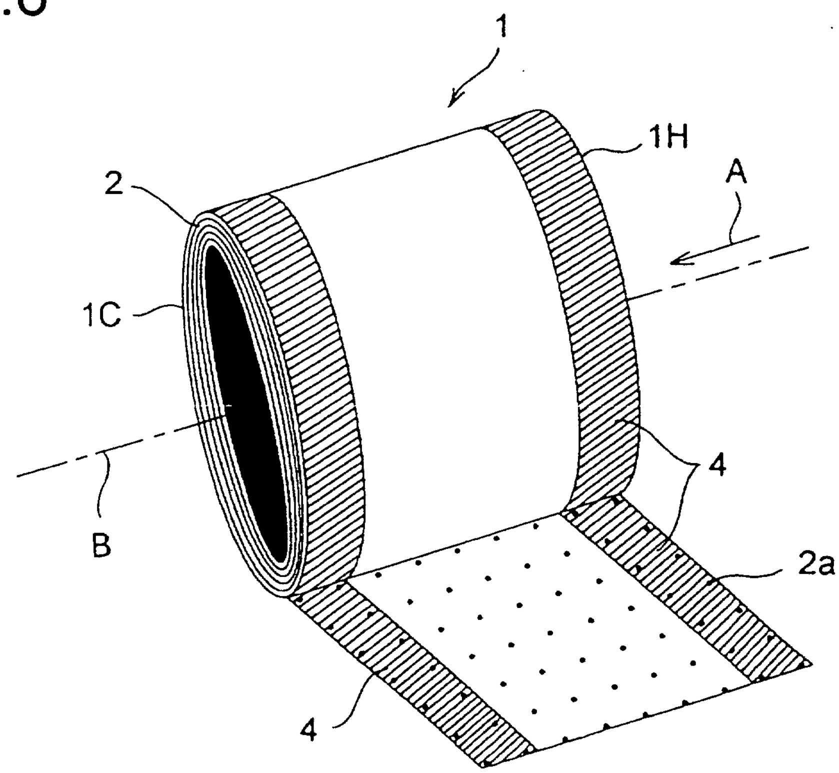


FIG.6



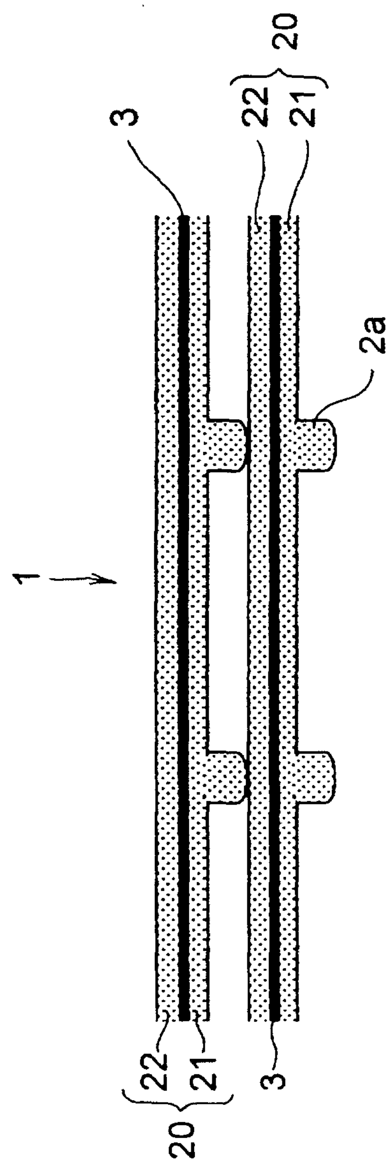


FIG.7

FIG.8

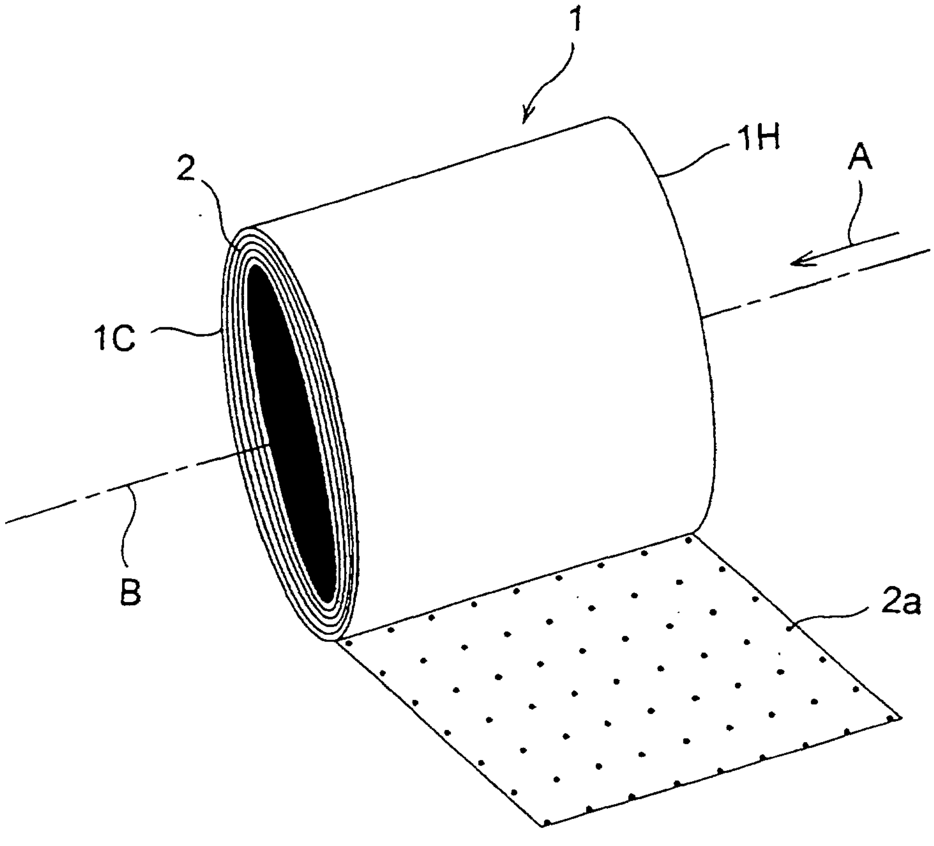
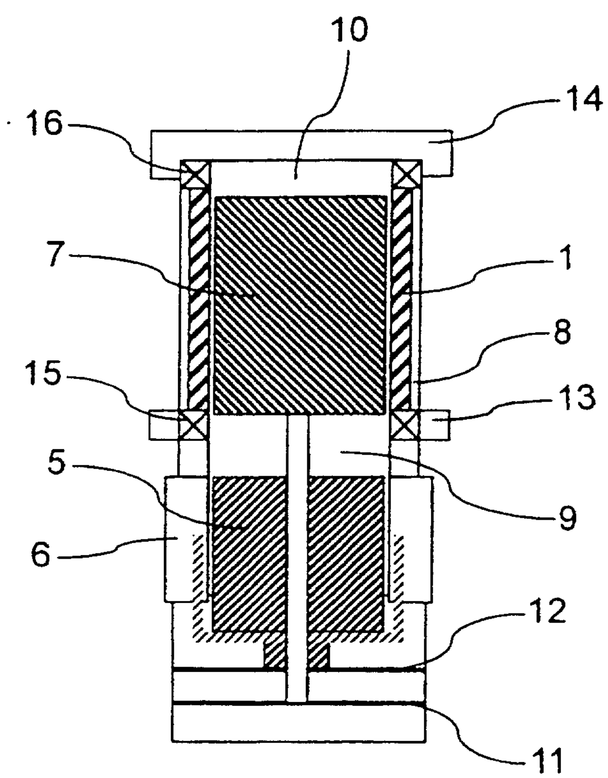


FIG.9



INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP02/08442

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl[7] F25B9/00, F02G1/057

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)
Int.Cl[7] F25B9/00, F02G1/057

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

Jitsuyo Shinan Koho	1926-1996	Jitsuyo Shinan Toroku Koho	1996-2002
Kokai Jitsuyo Shinan Koho	1971-2002	Toroku Jitsuyo Shinan Koho	1994-2002

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2000-220897 A (Sharp Corp.), 08 August, 2000 (08.08.00), Page 3, right column, lines 22 to 31 & EP 1024277 A2	1-7
A	JP 1-305271 A (Leybold AG), 08 December, 1989 (08.12.89), Page 3, lower left column, lines 14 to 20 & EP 339298 A1 & DE 3812427 A1	1-7

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Date of the actual completion of the international search
12 November, 2002 (12.11.02)

Date of mailing of the international search report
26 November, 2002 (26.11.02)

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