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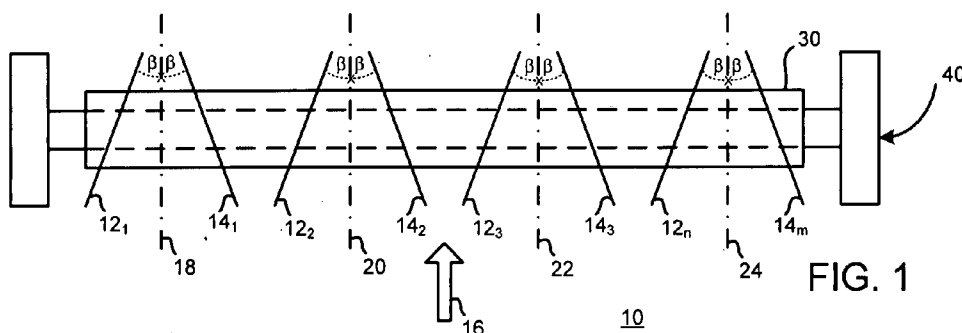


FIG. 1

(57) Abstract: An apparatus for generating vortexes in fluid flow generally adjacent to a surface includes: (a) at least one vortex generating element; and (b) a piezoelectric motor element coupled with the at least one vortex generating element. The piezoelectric motor element responds to a varying voltage signal to move the at least one vortex generating element between a first position extending into the fluid flow an operating distance from the surface and a second position generally flush with the surface.

APPARATUS AND METHOD FOR GENERATING VORTEXES IN FLUID FLOW ADJACENT TO A SURFACE

FIELD OF THE INVENTION

The present invention is directed to apparatuses and methods for affecting fluid flow adjacent to a surface, and especially to apparatuses and methods for generating vortexes in fluid flow adjacent to a surface.

BACKGROUND

5 Vortex generating elements may be employed with aircraft, ships or ground vehicles to reattach separated fluid flow across exterior surfaces. Reattaching fluid flow across exterior surfaces may improve control characteristics, decrease transonic drag and generally fine tune vehicle performance in a specific operating regime. Use of vortex generating units may be referred to as active flow control. Active flow control may advantageously deploy vortex
10 generating elements in a fluid stream adjacent to a surface, such as in the boundary layer of the fluid flow, at a locus upstream of the area of detached fluid flow. Vortex generating elements may be deployed only during certain evolutions such as, by way of example and not by way of limitation, during a steep climb, landing, take-off or transonic operation of an aircraft. Vortex generating elements may be deployed intermittently at a frequency that advantageously affects
15 downstream attached fluid flow.

There is a need for precise and rapid control of deployment of vortex generating elements to permit accurately effecting active flow control for a vehicle.

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SUMMARY

An apparatus for generating vortexes in fluid flow generally adjacent to a surface includes: (a) at least one vortex generating element; and (b) a piezoelectric motor element coupled with the at least one vortex generating element. The piezoelectric motor element responds to a varying voltage signal to move the at least one vortex generating element between a
25 first position extending into the fluid flow an operating distance from the surface and a second position generally flush with the surface.

A method for generating vortexes in fluid flow generally adjacent to a surface includes:
(a) In no particular order: (1) providing at least one vortex generating element; and (2) providing a piezoelectric motor element coupled with the at least one vortex generating element. (b) Operating the piezoelectric motor element responsive to a varying voltage signal to move the at least one vortex generating element between a first position extending into the fluid flow an operating distance from the surface and a second position generally flush with the surface.

Therefore, it is a feature of the present disclosure to provide precise and rapid control of deployment of vortex generating elements to permit accurately effecting active flow control for a vehicle.

Further features of the present disclosure will be apparent from the following specification and claims when considered in connection with the accompanying drawings, in which like elements are labeled using like reference numerals in the various figures, illustrating embodiments of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a top plan view of the apparatus of the present disclosure.

FIG. 2 is a side elevation view of the apparatus illustrated in FIG. 1.

FIG. 3 illustrates representative configurations for vortex generating elements useful with the apparatus of the present disclosure.

FIG. 4 is a flow chart illustrating the method of the present disclosure.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 is a top plan view of the apparatus of the present disclosure. In FIG. 1, a vortex generating apparatus 10 for affecting fluid flow adjacent to a surface may include a motor element 40, first vortex generating elements 12₁, 12₂, 12₃, 12_n and second vortex generating elements 14₁, 14₂, 14₃, 14_m. Motor element 40 may be coupled with first vortex generating elements 12₁, 12₂, 12₃, 12_n and second vortex generating elements 14₁, 14₂, 14₃, 14_m via a common carrier element 30. The indicators "n" and "m" are employed to signify that there can be any number of vortex generating elements in vortex generating apparatus 10. The inclusion of four first vortex generating elements 12₁, 12₂, 12₃, 12_n and four second vortex generating elements 14₁, 14₂, 14₃, 14_m in FIG. 1 is illustrative only and does not constitute any limitation

regarding the number of vortex generating elements that may be included in the vortex generating apparatus of the present invention.

Fluid flow in FIG. 1 may be in a direction indicated by an arrow 16. Fluid flow past first vortex generating element 12_1 may thereby be oriented substantially about a flow axis 18. Fluid flow past first vortex generating element 12_2 may be oriented substantially about a flow axis 20 parallel with flow axis 18. Fluid flow past first vortex generating element 12_3 may be oriented substantially about a flow axis 22 parallel with flow axis 18. Fluid flow past first vortex generating element 12_n may be oriented substantially about a flow axis 24 parallel with flow axis 18.

Each of first vortex generating elements 12_n may be angularly displaced to the left in FIG. 1 from a respective axis 18, 20, 22, 24 by an acute angle β .

Fluid flow past second vortex generating element 14_1 may thereby be oriented substantially about flow axis 18. Fluid flow past second vortex generating element 14_2 may be oriented substantially about flow axis 20. Fluid flow past second vortex generating element 14_3 may be oriented substantially about flow axis 22. Fluid flow past second vortex generating element 14_m may be oriented substantially about flow axis 24.

Each of first vortex generating elements 14_m may be angularly displaced to the right in FIG. 1 from a respective axis 18, 20, 22, 24 by acute angle β or by another acute angle.

Vortex generating apparatus 10 may employ only first vortex generating elements 12_n , may employ only vortex generating elements 14_m , may employ all of vortex generating elements 12_n , 14_m or may employ another combination of vortex generating elements 12_n , 14_m .

FIG. 2 is a side elevation view of the apparatus illustrated in FIG. 1. In FIG. 2, vortex generating elements 12_n , 14_m are illustrated in a deployed orientation extending through an enclosure 28. Enclosure 28 presents an outer surface 27 and an inner surface 29. Vortex generating elements 12_n , 14_m may traverse enclosure 28 through apertures or slots in enclosure 28 extending from inner surface 28 to outer surface 27 (apertures not shown). Vortex generating elements 12_n , 14_m may be attached with a common carrier element 32. Carrier element 30 may be coupled with motor element 40 via a connector element 34.

Motor element 40 may be configured as a piezoelectric motor element having a first tilt plate 42 movably coupled with a base member 46 at a first base connection locus 50, and having a second tilt plate 44 movably coupled at a second base connection locus 52 with base member 46. A buckled beam bias member 48 may be coupled with tilt plate 42 at a first bias locus 54

displaced from base connection locus 50. Buckled beam bias member 48 may also be coupled with tilt plate 44 at a second bias locus 56 displaced from base connection locus 52.

Motor element 40 may further include a piezoelectric element 60. Piezoelectric element 60 may be a bimorph piezoelectric element. A bimorph piezoelectric element may be a piezoelectric element having two active layers that produce a displacement of the element causing one active layer to extend and the other active layer to contract in response to an electrical signal applied to the element.

Piezoelectric element 60 may rest at a first position (indicated as piezoelectric element 60 in solid line format in FIG. 2) when an electrical signal +V is applied at a first terminus 62 of piezoelectric element 60 and an electrical signal -V is applied at a second terminus 64 of piezoelectric element 60. When in the first position, connector element 32 may urge carrier element 30 toward enclosure 28, vortex generating elements 12_n, 14_m may pass through apertures (not shown) in enclosure 28 to extend beyond outer surface 27 into the fluid flow along outer surface 27 (see arrow 16; FIG. 1).

Piezoelectric element 60 may rest at a second position indicated as piezoelectric element 60' in dotted line format in FIG. 2) when an electrical signal -V is applied at first terminus 62 of piezoelectric element 60 and an electrical signal +V is applied at second terminus 64 of piezoelectric element 60. Elements of motor element 40 in the second position of piezoelectric element 60 are indicated in dotted line format in FIG. 2 and designated using a "prime" notation. When in the second position, connector element 32' may urge carrier element 30' away from enclosure 28, vortex generating elements 12_n, 14_m may retract through apertures (not shown) in enclosure 28 to an orientation substantially flush with outer surface 27. In order to avoid cluttering FIG. 2, only a portion of carrier element 30' (carrier element in the second position of piezoelectric element 60') is included in FIG. 2.

The first position of piezoelectric element 60 may be referred to as a first equilibrium position, and the second position of piezoelectric element 60' may be referred to as a second equilibrium position.

Biasing piezoelectric element 60 using bias element 48 in cooperation with tilt plates 42, 44 and base member 46 permits motor element 40 to present enhanced displacement of piezoelectric element 60 in response to voltage signals applied at termini 62, 64. Operation of motor element 40 may be described in detail in co-pending U.S. Patent Application, Serial No. 11/584,305 filed October 20, 2006 for "ENHANCED DISPLACEMENT PIEZOELECTRIC

MOTOR” and assigned to the assignee of the present application. Directly coupling carrier element 30 with piezoelectric element 60 without any intervening transmission element permits rapid deployment of vortex generating elements 12_n , 14_m controlled by voltage signals applied to piezoelectric element 60. Eliminating a transmission element also may result in reduced cost and smaller size for vortex generating apparatus 10 as compared with other vortex generating apparatuses having similar operating characteristics.

FIG. 3 illustrates representative configurations for vortex generating elements useful with the apparatus of the present disclosure. In FIG. 3, a variety of exemplary shapes that may be employed as vortex generating elements are illustrated coupled with a carrier element 30 in a deployed orientation for affecting fluid flow adjacent to an outer surface 27 of an enclosure 28. It may not be advantageous to employ differently-shaped vortex generating elements in a single application; different configurations are illustrated in FIG. 3 attached to a common carrier element 30 for purposes of illustration only.

A rectangular vortex generating element 70 is similar in construction to vortex generating elements 12_n , 14_m (FIG. 2). A sloped rectangular vortex generating element 72 may be advantageously oriented to present a lower leading profile upstream into a fluid flow. Vortex generating element 74 may be a rod-shaped element. Vortex generating element 76 may be a Y-profile element. Vortex generating element 78 may be a truncated pyramid profile element.

Rod-shaped vortex generating element 74 may have any of several cross-section shapes. Cross-section of rod-shaped element 74 may be a substantially circular shape 80; an oval shape (not shown); a polygonal such as, by way of illustration and not by way of limitation, an octagonal shape 82, a “cross” shape 84, a pentagonal shape 86 or a triangular shape 88; or another shape.

FIG. 4 is a flow chart illustrating the method of the present disclosure. In FIG. 4, a method 100 for generating vortexes in fluid flow generally adjacent to a surface begins at a START locus 102. Method 100 may continue with, in no particular order: (1) providing at least one vortex generating element, as indicated by a block 104; and (2) providing a piezoelectric motor element coupled with the at least one vortex generating element, as indicated by a block 106.

Method 100 may continue with operating the piezoelectric motor element responsive to a varying voltage signal to move the at least one vortex generating element between a first position extending into the fluid flow an operating distance from the surface and a second position

generally flush with the surface, as indicated by a block 108. Method 100 may terminate at an END locus 110.

It is to be understood that, while the detailed drawings and specific examples given describe preferred embodiments of the disclosure, they are for the purpose of illustration only, 5 that the apparatus and method of the disclosure are not limited to the precise details and conditions disclosed and that various changes may be made therein without departing from the spirit of the disclosure which is defined by the following claims:

I Claim:

1. An apparatus for generating vortexes in fluid flow generally adjacent to a surface; the apparatus comprising:

(a) at least one vortex generating element (12);

(b) a piezoelectric motor element (40) coupled with said at least one vortex generating element; said piezoelectric motor element (40) responding to a varying voltage signal to move said at least one vortex generating element between a first position extending into said fluid flow an operating distance from said surface and a second position generally flush with said surface.

2. An apparatus for generating vortexes in fluid flow generally adjacent to a surface as recited in Claim 1 wherein said at least one vortex generating element (12) is a plurality of generally planar elements affixed with a common carrier element (30); said fluid flow occurring generally along a fluid flow axis; a first element group of said plurality of generally planar elements extending into said fluid flow substantially in a parallel orientation at a first acute angle in a first direction from said fluid flow axis in said first position; a second element group (14) of said plurality of generally planar elements extending into said fluid flow substantially in a parallel orientation at a second acute angle in a second direction from said fluid flow axis in said first position; said piezoelectric motor element (40) being coupled with said common carrier element.

3. An apparatus for generating vortexes in fluid flow generally adjacent to a surface as recited in any of Claims 1 and 2 wherein said at least one vortex generating element (12) is a plurality of generally rod-shaped elements affixed with a common carrier element (30); said plurality of rod-shaped elements extending into said fluid flow in said first position; said piezoelectric motor element (40) being coupled with said common carrier element.

4. An apparatus for generating vortexes in fluid flow generally adjacent to a surface as recited in any of Claims 1-3 wherein said piezoelectric motor element (40) includes a bimorph piezoelectric element coupled for receiving said voltage signal and a buckled beam bias member (48) coupled for biasing said piezoelectric element to either of a first stable position and a second stable position in response to said voltage signal; said at least one vortex generating element being in said first position when said piezoelectric element is in said first stable position; said at

least one vortex generating element being in said second position when said piezoelectric element is in said second stable position.

5 5. An apparatus for generating vortexes in fluid flow generally adjacent to a surface as recited in any of Claims 1-4 wherein said carrier element (30) is situated generally proximate to an interior surface substantially adjacent to said exterior surface.

6. A method for generating vortexes in fluid flow generally adjacent to a surface; the method comprising:

10 (a) in no particular order:

 (1) providing at least one vortex generating element (12); and

 (2) providing a piezoelectric motor element (40) coupled with said at least one vortex generating element; and

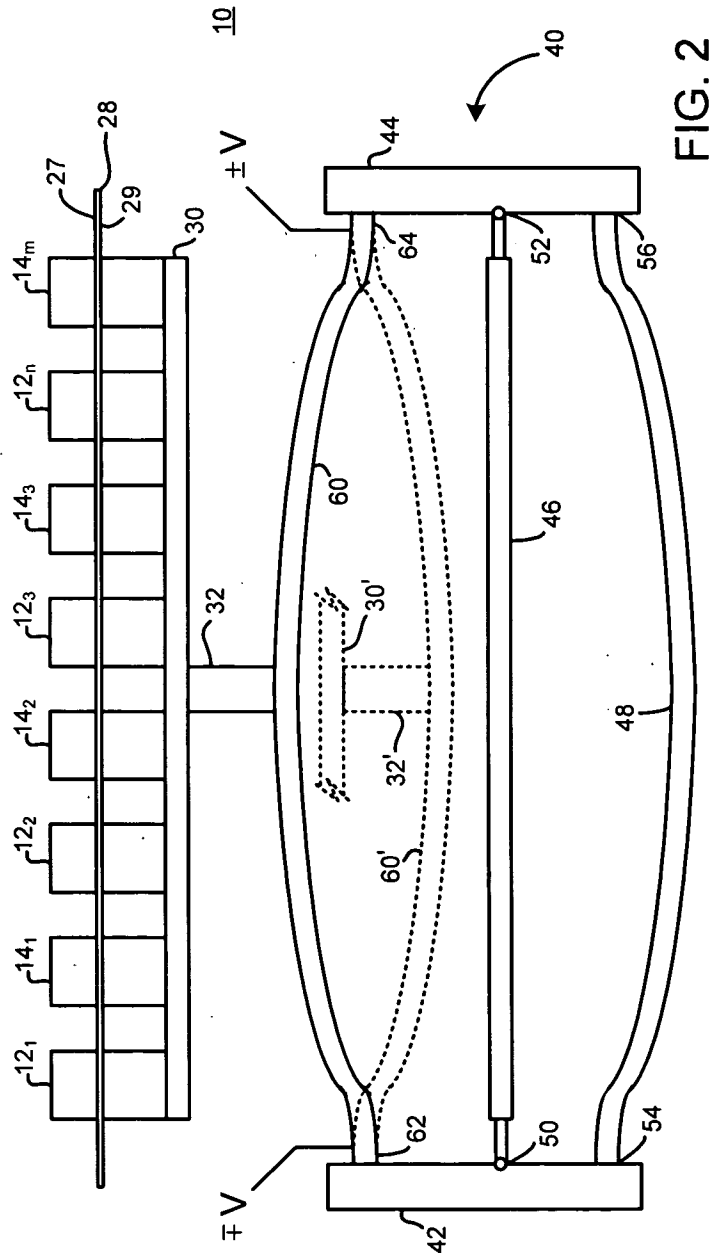
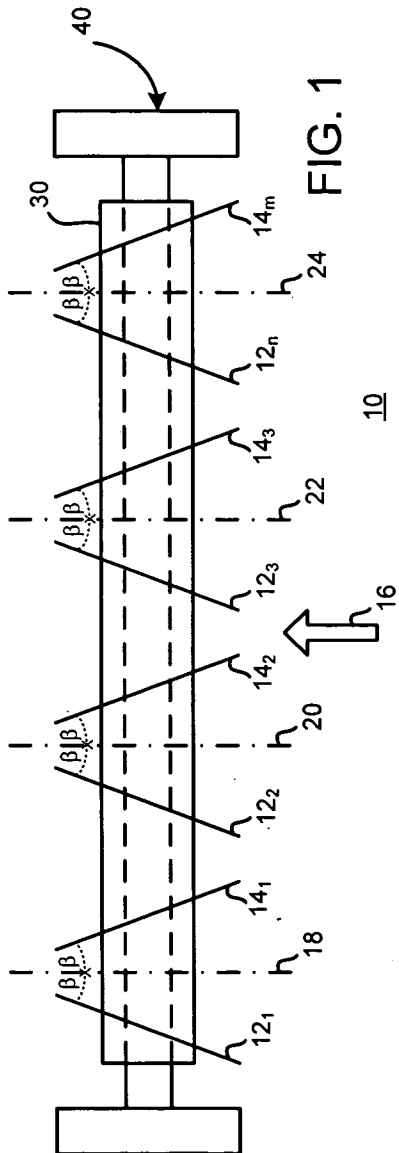
15 (b) operating said piezoelectric motor element (40) responsive to a varying voltage signal to move said at least one vortex generating element between a first position extending into said fluid flow an operating distance from said surface and a second position generally flush with said surface.

20 7. A method for generating vortexes in fluid flow generally adjacent to a surface as recited in Claim 6 wherein said piezoelectric motor element (40) includes a bimorph piezoelectric element coupled for receiving said voltage signal and a buckled beam bias member (48) coupled for biasing said piezoelectric element to either of a first stable equilibrium position and a second stable equilibrium position in response to said voltage signal; said at least one vortex generating element (12) being in said first position when said piezoelectric element is in
25 said first stable equilibrium position; said at least one vortex generating element being in said second position when said piezoelectric element is in said second stable equilibrium position.

30 8. A method for generating vortexes in fluid flow generally adjacent to a surface as recited in any of Claims 6 and 7 wherein said at least one vortex generating element (12) is a plurality of generally planar elements affixed with a common carrier element (30); said fluid flow occurring generally along a fluid flow axis; said plurality of generally planar elements extending into said fluid flow substantially in a parallel orientation at an acute angle with said fluid flow

axis in said first position; said piezoelectric motor element (40) being coupled with said common carrier element.

9. A method for generating vortexes in fluid flow generally adjacent to a surface as
5 recited in any of Claims 6-8 wherein said at least one vortex generating element (12) is a plurality of generally planar elements affixed with a common carrier element (30); said fluid flow occurring generally along a fluid flow axis; a first element group of said plurality of generally planar elements extending into said fluid flow substantially in a parallel orientation at a first acute angle in a first direction from said fluid flow axis in said first position; a second element
10 group of said plurality of generally planar elements extending into said fluid flow substantially in a parallel orientation at a second acute angle in a second direction from said fluid flow axis in said first position; said piezoelectric motor element (40) being coupled with said common carrier element.



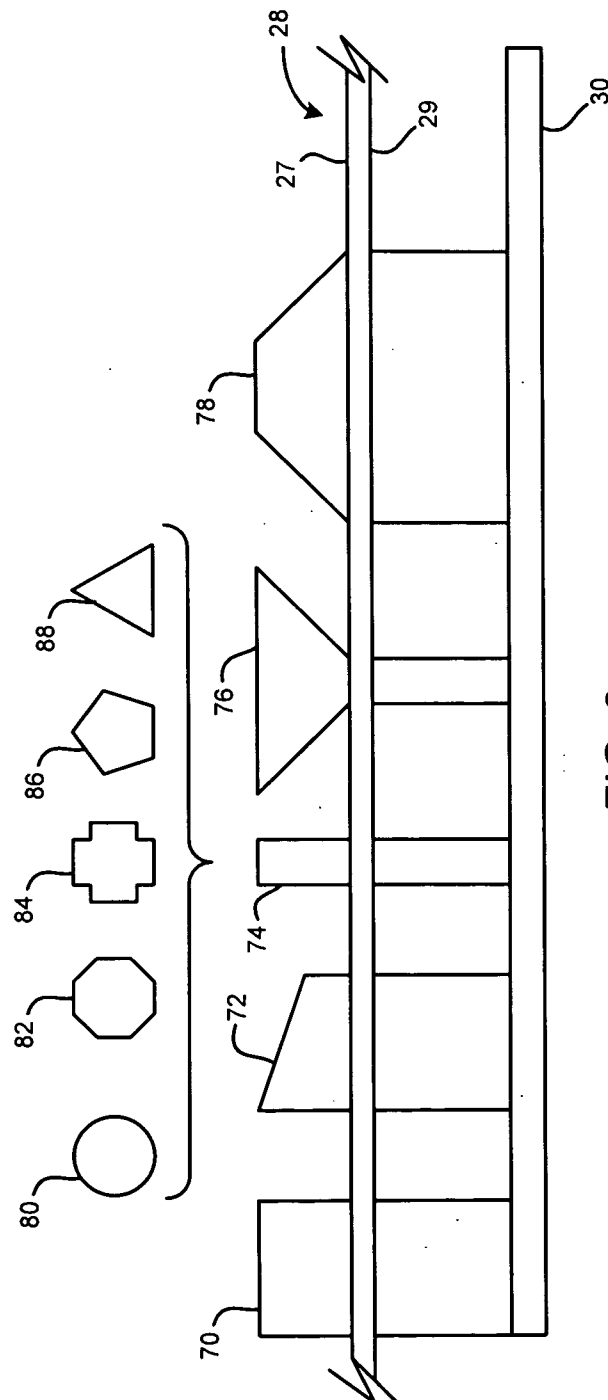


FIG. 3

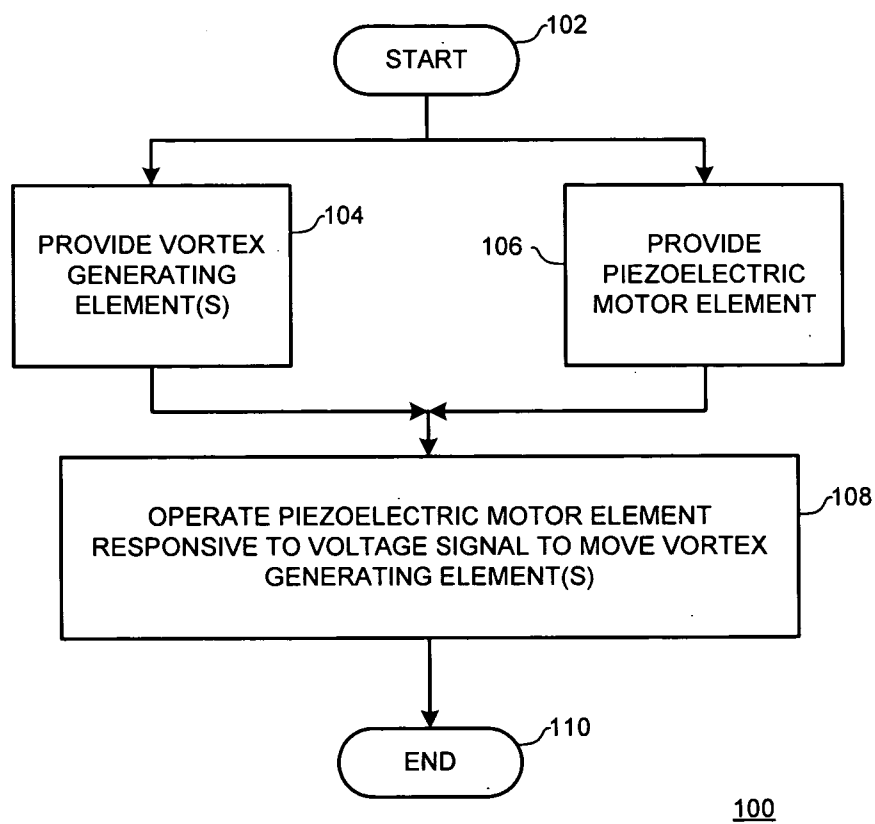


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2008/078330

A. CLASSIFICATION OF SUBJECT MATTER
INV. B64C23/06

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)
B64C

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X Y	US 5 785 282 A (WAKE BRIAN E [US] ET AL) 28 July 1998 (1998-07-28) page 7, line 9 - line 52	1,4,6,7 2,5,8,9
Y	US 6 105 904 A (LISY FREDERICK J [US] ET AL) 22 August 2000 (2000-08-22) the whole document	2,3,5,8, 9
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☒ 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

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INTERNATIONAL SEARCH REPORT

International application No

PCT/US2008/078330

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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