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(54) Title: REINFORCING TEXTILE COMPLEX FOR COMPOSITE PARTS, AND COMPOSITE PARTS INTEGRATING SAID COMPLEX

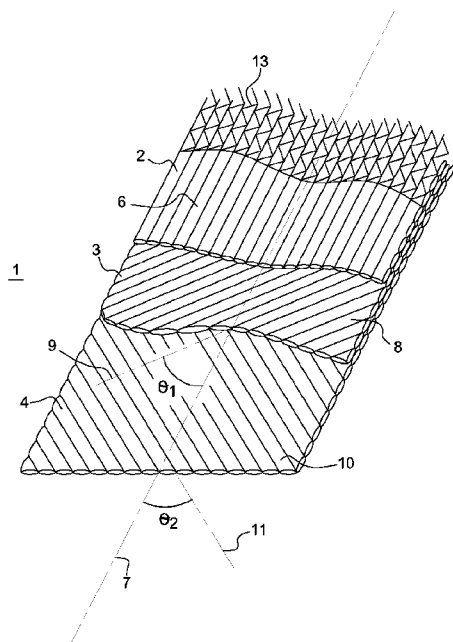


Fig. 1

(57) Abstract: A reinforcing textile complex for a composite part, including several layers of high-tenacity yarns, said yarns being arranged in parallel fashion within each layers, with no crimp, that is: a first layer having its yarns oriented along a reference direction; a second layer having its yarns oriented along a direction forming a first non-zero angle with the reference direction; a third layer having its yarns oriented along a direction forming a second angle with the reference direction, said first and second angles being of opposite directions, the layers being assembled by sawing, knitting or gluing, characterized in that the second and the third layers differ by at least one parameter selected from the group including: the absolute value of the angle of the direction of the yarns with respect to the reference direction, the mass per unit area, -the material forming the yarns of said layers.



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**REINFORCING TEXTILE COMPLEX FOR COMPOSITE PARTS, AND COMPOSITE PARTS
INTEGRATING SAID COMPLEX**

BACKGROUND

The present disclosure relates to the field of technical textiles, and more specifically to textiles used to manufacture composite material, where the textile material is associated with a matrix, generally of thermosetting type.

It more specifically aims at a multiaxial reinforcing complex, having a specific geometry enabling to optimize the mechanical properties of composite parts integrating it. Such a textile complex may have multiple applications. The aeronautical, automobile, or aerospace industry, the manufacturing of wind generators, and in particular of wind generator blades, or again of parts used in off-shore extraction installations should especially be mentioned, without this being a limitation.

PRIOR ART

In the field of composite materials, the used textile reinforcing layers are intended to provide mechanical properties having a geometric definition directly depending on the direction of the yarns forming the textile reinforcing layer. Thus, textile reinforcing layers may comprise one or several assemblies of high-tenacity yarns, following preferred directions.

Generally, to provide an orthotropic behavior of the formed composites, the different yarns assemblies are distributed in an angularly balanced way. However, a constant angular distribution may not be optimal in certain configurations, especially in composite parts which are strained by variable loads according to directions.

Further, textile reinforcing structures capable of providing high mechanical properties may have various designs. Thus, textile reinforcing layers based on woven yarns, where the yarns of different directions are interlaced, are known.

As described in document WO 2010/014342, textile structures formed of sheets of parallel rectilinear yarns associated in different ways, without for the yarns to be interlaced, are also known. This type of structure, currently called NCF (*Non Crimp Fabric*) has the advantage of having perfectly rectilinear yarns, and thus with no crimp, which thus optimally express their mechanical properties.

An object of the present invention is to enable the forming of reinforcing layers with a high mechanical performance, in particular to form elongated or the like composite parts.

Relating to the specific application to wind generator blades, such structures are known to be likely to be submitted to a high mechanical stress, and this all the more as they are large and very elongated. Thus, the maintaining of a high mechanical performance generally requires, with existing solutions, an oversizing of supporting structures, as well compromises in terms of lifetime.

SUMMARY

The present invention thus relates to a reinforcing textile complex for composite parts, which comprises several layers of high-tenacity yarn. The yarns are arranged in parallel fashion within each layer and with no crimp, and the layers are assembled together by any means, such as sawing, knitting, or gluing.

The complex comprises at least three different layers, that is:

- a first layer having its yarns oriented along a reference direction;
- a second layer having its yarns oriented along a direction forming a first non-zero angle with the reference direction;
- a third layer having its yarns oriented along a direction forming a second angle with the reference direction, the first and the second angle being of opposite directions, and having an absolute value less than 60° .

According to the present invention, the complex characterizes in that the second and the third layers differ by at least one parameter selected from the group comprising:

- the absolute value of the angle of the yarns direction with respect to the reference direction,
- mass per unit area,
- the material forming the yarns of said layers.

In other words, the present invention comprises combining several NCF-type layers by selecting parameters in relation with the geometry of the elementary layers, that is, their orientation, their mass, or their intrinsic properties by the selection of the material, to obtain a generally anisotropic material.

Several execution modes are possible to obtain this result.

Thus, in a first family of embodiments, the angles of the yarns of the second and third layers are different, and in particular different in absolute value by more than 5° , to obtain a measurable effect.

In other words, the reinforcing complex thus has an anisotropic structure, or more generally properties that cannot be deduced by symmetry around a median plane including the reference direction, since the different layers forming it are arranged with clearly different angles between one another. Such a complex being anisotropic can be referred as an “unbalanced” complex.

Due to this specific configuration, the mechanical properties of composite parts integrating such reinforcing complexes can be optimized. Thus, the Applicants have found that due to the difference between the angles formed by the yarns of the oriented layers and the reference direction, advantage is taken from a coupling effect between bending and twisting deformations around the reference direction, while keeping good mechanical properties. The use of the third layer, arranged with an opposite orientation, contributes to increasing the torsion or flexion resistance, while keeping, due to the difference between the absolute values of the two angles, a coupling phenomenon between bend and twist phenomena.

As an example, such a coupling may advantageously be used in elongated structures used in a fluid medium and submitted to variable loads, such as wind generators. In this case, the coupling for example enables to modify the pitch angle of a wind generator blade, without requiring an active system and/or a complex mechanical connection, since the structure passively deforms according to the applied load. By varying the two angles and selecting the materials, and in particular their nature or their thickness, it is possible to act on different mechanical parameters of the structures by incorporating such reinforcing layers, in particular by varying various parameters such as:

- the axial stiffness;
- the shear stiffness;
- the strengths in a positive or negative shear direction;
- the coupling between twist and bend phenomena;
- the critical buckling load;
- the fatigue of the material.

In practice, satisfactory results are obtained when the angle formed by the second direction ranges between 10° and 35° , and preferentially between 15° and 25° . As a complement, satisfactory results are obtained when the angle of the third layer with respect to the reference direction is between 25° and 60° , in the opposite direction with respect to the reference direction. The selection of the different angles enables to favor one or several mechanical parameters of the composite integrating the reinforcing layer.

In practice, the used high-tenacity yarns may be formed of different materials, and in particular, without this being a limitation, carbon, glass, aramide, basalt, or even natural fibers such as linen.

To promote given properties, it is possible to form reinforcing layers having their different elementary layers or folds formed of yarns which are either identical or different, with all possible combinations between layers.

In another family of embodiments, it is possible to use oriented layers with identical angles, symmetrical with respect to the reference direction, but having variable thicknesses and/or masses per unit area.

In other words, it is possible to use layers having different individual masses per unit area, here again with all possible combinations as to the distribution of masses per unit area for each of the individual layers. It has been observed that differences on the order of 10% between the masses of the different layers may have an effect on the mechanical performance of composite parts integrating such reinforcing layers.

In another family of embodiments, it is possible to use oriented layers which mechanically differ by the mechanical properties of the materials forming the yarns. Thus, by forming hybrid structures, for example combining glass and carbon, an anisotropic structure may be obtained.

It is of course possible to combine several of the above-mentioned parameters to optimize the mechanical properties of the part integrating the textile reinforcing layer, by varying both the angles of the oriented layers, the relative mass per unit area of the different layers, and the materials used, or two of these parameters only, in order to obtain an unbalanced structure.

According to applications, the complex may be used either alone, or in combination with other identical or different complexes, to form stacks.

In the case of a stack of at least two identical complexes, solutions where all the stacked complexes have reference directions oriented in the same direction will be preferred. In other words, a stack will be formed by aligning the 0° directions of the different superposed layers.

Similarly, relating to stacks of identical complexes, various association modes can be envisaged, and in particular so-called “symmetrical” stacks, where the layers in contact, from one elementary complex to the other, have the same orientation. In other words, the stacking of the different complexes is performed by flipping every other complex, to have a stack symmetrical with respect to a mid-thickness plane.

It is also possible to form “direct” stacks, wherein the different complexes have are arranged absolutely identically, thus resulting in “non symmetrical” composites.

Although the simplest solution is to use complexes only including the three mentioned layers, in certain variations, it is also possible to include additional layers.

BRIEF DESCRIPTION OF THE DRAWINGS

The implementation and other features and advantages of the present invention will be discussed in detail in the following non-limiting description of embodiments in connection with the accompanying drawings.

- Figure 1 is a simplified perspective view of a textile complex according to a first embodiment of the present invention.
- Figure 2 is a simplified perspective view of an installation enabling to manufacture the complex of Figure 1.
- Figure 3 is an exploded simplified perspective view of a stack of several complexes of Figure 1.
- Figure 4 is a flowchart illustrating the different calculations enabling to assess the mechanical properties of composites incorporating complexes according to the present invention.
- Figures 5A to 5F are graphs where the abscissas and ordinates correspond to values of orientation angles of the yarns of the second and third layers, and which have

iso-level curves for the values of the following mechanical parameters:

- the axial stiffness;
 - the shear stiffness;
 - the positive shear strength;
 - the negative shear strength;
 - the coupling between twist and bend phenomena;
 - the critical buckling load;
 - a fatigue criterion for the material.
- Figures 6A to 6L, 7A to 7D, 8A to 8E, 9A to 9E, 10A to 10F are Kiviat diagrams showing for five series of examples the values of different mechanical parameters compared with values of a reference example.

DESCRIPTION OF EMBODIMENTS

As already discussed, the present invention relates to a textile reinforcing complex, an example of which is schematically illustrated in Figure 1.

In the illustrated form, complex **1** comprises three different layers **2**, **3**, **4**, assembled to form an element that can be individually handled, for its drape molding in a composite part manufacturing mold, alone or in association with one or other identical or different reinforcing layers.

As illustrated in Figure 1, reinforcing layer **1** comprises a first layer **2** illustrated as the top layer, and formed of torsion-free high-tenacity yarns **6** possibly transversely spread in the case of thin reinforcing layers, in particular based on carbon. The yarns are arranged in parallel fashion in the form of sheets, while being as rectilinear as possible and with no crimp due to perpendicular weft yarns.

Such yarns may in particular be glass or carbon yarns, having properties selected in relation with the desired mechanical performance and for economical reasons.

Glass may be mentioned as an example, and especially that sold by *3B-The Fiberglass* under reference *SE1500*, or again carbon yarns sold under trade name *T700* by *TORAY*.

Of course, the concept of the present invention may be declined for any type of high-tenacity yarns, possibly including yarns combining several different materials or yarns of different natures such as carbon and glass, associated in a same layer.

As illustrated in Figure 1, yarns **6** of first layer **2** are oriented along a so-called reference direction **7**, which, by convention, is angle 0° for the calculation of the orientations of the other layers.

Complex **1** also comprises a second layer **3** formed with yarns **8** also of same tenacity, which may be identical to or different from those **6** of first layer **2**. Yarns **8** are oriented along a direction **9** which forms an angle θ_1 with reference direction **7**. Angle θ_1 is selected to be relatively small, that is, between 10° and 35° , as compared with the angles generally observed in multiaxial reinforcing layers.

Third layer **4** of complex **1** of Figure 1 is also formed of high-tenacity yarns **10**, which may also be similar to or different from yarns **6**, **8** of the two other layers. The yarns are oriented along a direction **11** which forms an angle θ_2 with respect to reference direction **7**. The direction of angle θ_2 is opposite to that of angle θ_1 , so that directions **8**, **11** of the second and of the third layers **3**, **4** are on either side of reference direction **7**.

In practice, angle θ_2 formed by the yarns of the third layer differs, in absolute value, from angle θ_1 , and is greater, typically ranging between 25° and 60° . The influence of the different angles will be detailed hereinafter.

The different layers of the complex may be associated in various ways, and in particular as illustrated in Figure 1 by sawing yarns **13** according to a conventional MALIMO-type technique. Other means for assembling the different layers may be used, and especially techniques using adhesive materials capable of being deposited on a fraction of the surface of the different layers.

Techniques where melt able materials are deposited between layers before being exposed to temperature and/or pressure conditions causing their melting, and accordingly the bonding of the stacked layers with one another, may also be used.

In particular, such a complex may be formed on installation **30** illustrated in Figure 2. Such an installation **30** comprises a conveyor **31** having the different layers deposited thereon from four successive stations **40**, **50**, **60**, **70**. Thus, first station **40** delivers from a creel **41** high-tenacity yarns **42** to form the third layer of the complex of Figure 1. The different yarns are conventionally brought close to the conveyor via wefting device **44** which enables to deposit successive strips **45** of parallel yarns, with orientation θ_2 .

A similar second station **50** enables to deposit sheets of yarns **55** with an orientation θ_1 corresponding to the second layer of the complex of Figure 1. In the case where the anisotropy of the reinforcing layer results from the selection of the angles of the oriented layers, angle θ_1 is selected to be different from angle θ_2 . In the case where this anisotropy results from other factors, such as the mass of the layers or the intrinsic properties of the materials used, the two oriented layers may be directed symmetrically with respect to the reference direction, in which case the two angles θ_2 and θ_1 are selected to be identical.

The two layers are conveyed forward by conveyor **31** and reach third station **60**, where they are then covered with the first layer, having its yarns delivered from third canter **61**, and which are oriented along the reference direction, that is, the forward direction of conveyor **31**. The different superposed sheets then arrive at the level of a sawing station **70** which enables to assemble the different layers, to make the complex easier to handle on manufacturing of the composite parts that it integrates.

It should be noted that the order in which the layers are superposed within the complex may be different from that shown in Figure 2, since it may in particular be influenced by the way in which the different layers are united. Indeed, in the case of an association by sawing, according to the used sawing head, it may be more convenient for the layer having yarns along the reference direction not to be under the stack. Apart from this constraint, the different layers may be indifferently arranged. The type of sawing, the stitch and the space between stitches are selected to provide an optimal cohesion between the assembled layers.

It should also be noted that the mass per unit area of each of the layers may be variable, to favor the contribution of one or several layers within the complex, as will be shown by the detailed examples described hereinafter.

The complex according to the present invention may be used in different ways, that is, alone or in combination with other identical or different complexes.

Thus, as illustrated in Figure 3, complex **101** formed of three elementary layers may be superposed in several layers. In the illustrated form, stack **100** is formed "symmetrically", that is, opposite layers **105**, **106**; **107**, **108**; **109**, **110** from one complex to the other have the same orientation, so that stack **100** is symmetrical with respect to its plane located at mid-thickness.

Of course, the number of elementary layers may be adapted according to the application and to the desired mechanical properties. It is also possible to integrate within the stack other types of complexes, which have properties similar to or different from those of the complex of Figure 1, according to the desired result.

The Applicants have observed that the complex according to the present invention enables to form composite parts which have a better mechanical performance, for a smaller weight.

There may be a lot of advantageous mechanical properties of composite parts integrating complexes according to the present invention, and the capacity of setting both the angles of the orientation of the two inclined layers, as well as their specific mass per unit area, or the intrinsic properties of the materials used, enable to vary all or part of the different general mechanical properties.

Such mechanical properties may be either directly measured on real parts, or again be estimated by simulations implementing mathematical calculations, or based on the intrinsic properties of the materials used and the different conventional theories in laminated structure calculation.

Figure 5 illustrates a simplified algorithm of the different steps enabling to calculating the main mechanical properties of a composite part integrating reinforcing layer complexes according to the present invention. This calculation requires knowing the properties of each of the materials of the layers forming the complexes, and in particular the longitudinal and transverse elongation modules (E_x , E_y) of the materials forming the high-tenacity yarns, as well as the shear modulus (E_s) and the Poisson's coefficient (ν) of the same material.

Based on these intrinsic data and on thickness e of each of the layers, it is possible to develop a compliance matrix of each layer at a first step **201**. Then, inverting this matrix provides the stiffness matrix calculated along the yarn axis. In a subsequent step **202**, based on this stiffness matrix along the yarn axis, the stiffness matrix along the reference direction is calculated by using the values of angles θ_1 and θ_2 formed by the yarns of the oriented layers with respect to the reference direction.

At a subsequent step **203**, based on the different thicknesses and thus on coordinates Z_k of each of the elementary layers, a so-called “ABD” matrix providing the twist and bend stiffnesses of the stack is determined.

At a subsequent step **204**, it is possible to extract from the “ABD” matrix the main values useful for the sizing of laminated composite structures, and in particular elongation coefficient E_1 in the reference direction of the composite part, shear modulus E_6 in the plane of the composite structure, and coefficient B/T , corresponding to the coupling between the above-mentioned bend and twist phenomena. Factor B/T corresponds to the ratio of coefficients a_{16}/a_{11} of the “ABD” matrix where a_{11} is the proportionality factor between longitudinal extension ε_1 and stress σ_1 applied in the longitudinal direction of the composite structure, coefficient a_{16} being the ratio of shear deformation ε_6 to the same longitudinal stress σ_1 .

Further, based on matrix D_{eff} extracted from the “ABD” matrix, a critical buckling load P_{cr} is calculated. This critical buckling load calculation takes into account the values of axial load N_1 and shear load N_6 assessed in the active configuration of the composite part. As an example, for an application to the forming of wind generator blades, it is assumed that axial load N_1 is equal to approximately 10 times shear load N_6 .

As illustrated in Figure 5, the calculations of the properties of the structure may also enable, in a complementary step **301**, to measure the general deformation of the composite part, based on the axial load and shear load values N_1 , N_6 applied to the structure. Based on these general values, it is possible, in a subsequent step **302**, to determine the deformation values of each layer, along the direction of longitudinal load N_1 , according to the coordinates of each elementary layer. At a subsequent step **303**, the deformation values of each of the layers can then be deduced according to the orientation of the yarns of each layer, along the direction of the yarns of each layer. Then, at step **304**, the strain applied at the level of each layer can be deduced. It is then possible, at step **305**, by applying an adequate rupture criterion, and for example PUCK’s criterion, to determine the shear strength of each layer. Then, at a step **306** the shear strength of the general structure is determined by taking into account the layers for which the rupture criterion is the most critical. The shearing strengths thus determined differ according to the shear direction.

The fatigue is assessed by considering the fatigue properties of the matrix and of the fibers. Such fatigue predictions are made according to standard GL (Germanischer Lloyd Industrial Services GmbH) methods. The results of this calculation method are a number corresponding in logarithmic scale to a number of cycles before failure.

Various embodiments have been simulated, by using either glass yarns, or carbon yarns, in association with a specific core layer. More specifically, the above-mentioned calculations have used the following characteristics.

Glass:

Longitudinal and transverse elasticity modulus: 74 GPa

Shear modulus: 30.8 GPa

Poisson's ratio: 0.2

Tensile strength: 1,814 MPa

Compressive strength: 1,614 MPa

Carbon:

Longitudinal elasticity modulus: 230 GPa

Transverse elasticity module: 19 GPa

Poisson's ratio: 0.2

Shear modulus in plane 1-2: 27 GPa

Shear modulus in plane 2-3: 7 GPa

Tensile strength: 4,250 MPa

Compressive strength: 2,450 MPa

The used matrix has the following properties:

Longitudinal and transverse elasticity modulus: 3.35 GPa

Shear modulus : 1.24 GPa

Poisson's ratio: 0.35

Tensile strength: 68.3 MPa

Compressive strength: 130 MPa

The graphs of Figures 5A to 5G have been plotted from simulations calculated for glass-based composites, comprising a first 0° layer, weighting twice as much as each of the inclined layers having variable parameters as orientation angles. The angles are indicated in absolute value, it being understood that they are oriented in opposite directions, on either side of the reference direction.

Figure 5A thus shows that the axial stiffness is maximum when the oriented layers are closest in angle to the reference direction. Conversely, the axial stiffness decreases when the directions of the oriented layers form an angle approaching 90° .

Figure 5B shows that the shear stiffness is maximum for a configuration where the angles of the oriented layers are close to $+45^\circ$ and -45° respectively. It should also be noted that for a layer having an angle close to 25° , the shear stiffness is maximum when the angle of the other layer is close to 40° , measured in the opposite direction.

Figures 5C and 5D show that the positive or negative shear strength is maximum when one of the layers is oriented close to 20° , for a very small inclination of the other layer.

Figure 5E shows that the coupling coefficient between bending and twisting is zero for angles symmetrical with respect to the reference direction. It should also be noted that for a layer which has an orientation on the order of 25° , the coupling coefficient is all the larger as the other layer is oriented with a large angle with respect to the reference direction.

Figure 5F shows that the critical buckling load is maximum for a configuration when the two layers are oriented at $+45^\circ$ and -45° . It should also be noted that for a layer which has an orientation on the order of 25° , the critical buckling load has a maximum when the other layer is oriented with an angle close to 45° with respect to the reference direction.

Figure 5G shows that the fatigue criterion is maximum when the angles of the oriented layers are small.

Examples 1 to 12

The following table provides the values of the different simulated parameters for 12 examples of composite parts where the angles of the different layers are variable. In these 12 examples, the mass per unit area of the layer oriented along the reference direction is twice the mass of each of the layers having non-zero orientations. The last column of this table indicates a way to describe such a complex, by listing the angles formed by each of the layers, it being specified that the indexes indicate the relative weight of the concerned layer. Further, in the absence of a letter after the angle figures, the material of the concerned layer is glass by convention. The use of carbon in one of the layers is indicated by letter C following the angle of the concerned layer.

Example N°	Angle (θ_1) of the 2 nd layer	Angle (θ_2) of the 3 rd layer	Conventional representation
1	+10°	-30°	0 ₂ /+10/-30
2	+10°	-45°	0 ₂ /+10/-45
3	+10°	-60°	0 ₂ /+10/-60
4	+15°	-30°	0 ₂ /+15/-30
5	+15°	-45°	0 ₂ /+15/-45
6	+15°	-60°	0 ₂ /+15/-60
7	+20°	-30°	0 ₂ /+20/-30
8	+20°	-45°	0 ₂ /+20/-45
9	+20°	-60°	0 ₂ /+20/-60
10	+25°	-30°	0 ₂ /+25/-30
11	+25°	-45°	0 ₂ /+25/-45
12	+25°	-60°	0 ₂ /+25/-60

The following table indicates the values of different mechanical parameters for a sandwich structure comprising two textile complexes defined by the above table, between which a core layer having an 8-millimeter thickness is interposed.

Example N°	Conventional representation	A: Axial stiffness (Pa)	B: Shear stiffness (Pa)	C: Positive shear strength (Pa)	D: Negative shear strength (Pa)	E: Bend/twist coupling	F: Critical buckling load (N/m)	G: Fatigue criterion
1	0 ₂ /+10/-30	4.34.10 ¹⁰	5.95.10 ⁹	3.13.10 ⁵	8.32.10 ⁵	1.99.10 ⁻¹	4.98.10 ⁴	5.19
2	0 ₂ /+10/-45	4.03.10 ¹⁰	6.15.10 ⁹	2.48.10 ⁵	4.53.10 ⁵	-8.52.10 ⁻³	5.60.10 ⁴	5.04
3	0 ₂ /+10/-60	3.87.10 ¹⁰	5.34.10 ⁹	2.10.10 ⁵	3.14.10 ⁵	-2.44.10 ⁻¹	5.44.10 ⁴	4.96
4	0 ₂ /+15/-30	4.26.10 ¹⁰	6.34.10 ⁹	3.52.10 ⁵	6.19.10 ⁵	8.34.10 ⁻²	5.11.10 ⁴	5.16
5	0 ₂ /+15/-45	3.92.10 ¹⁰	6.53.10 ⁹	2.70.10 ⁵	4.34.10 ⁵	-1.15.10 ⁻¹	5.68.10 ⁴	4.99
6	0 ₂ /+15/-60	3.74.10 ¹⁰	5.67.10 ⁹	2.21.10 ⁵	3.01.10 ⁵	-3.52.10 ⁻¹	5.53.10 ⁴	4.89
7	0 ₂ /+20/-30	4.14.10 ¹⁰	6.79.10 ⁹	3.82.10 ⁵	5.09.10 ⁵	1.23.10 ⁻²	5.28.10 ⁴	5.10
8	0 ₂ /+20/-45	3.78.10 ¹⁰	7.00.10 ⁹	2.85.10 ⁵	4.13.10 ⁵	-1.76.10 ⁻¹	5.78.10 ⁴	4.93
9	0 ₂ /+20/-60	3.59.10 ¹⁰	6.10.10 ⁹	2.27.10 ⁵	2.87.10 ⁵	-4.08.10 ⁻¹	5.63.10 ⁴	4.78
10	0 ₂ /+25/-30	4.00.10 ¹⁰	7.25.10 ⁹	3.95.10 ⁵	4.42.10 ⁵	-1.32.10 ⁻²	5.48.10 ⁴	5.04
11	0 ₂ /+25/-45	3.63.10 ¹⁰	7.53.10 ⁹	2.90.10 ⁵	3.73.10 ⁵	-1.94.10 ⁻¹	5.89.10 ⁴	4.82
12	0 ₂ /+25/-60	3.44.10 ¹⁰	6.61.10 ⁹	2.27.10 ⁵	2.73.10 ⁵	-4.17.10 ⁻¹	5.73.10 ⁴	4.66

Figures 6A to 6L are 12 diagrams where each of the criteria of the above table are listed for each concerned example, after having been normalized with respect to the values assessed on a conventional structure. This structure is obtained from glass yarns and comprises oriented layers forming angles of $+45^\circ$ and -45° , and a layer at 0° which weighs twice as much as each of the oriented layers. The diagrams also comprise a plot for this conventional structure, to make the comparison easier. The criteria for this conventional structure are listed in the following table.

Conventional representation	A: Axial stiffness (Pa)	B: Shear stiffness (Pa)	C: Positive shear strength (Pa)	D : Negative shear strength (Pa)	E: Bend/twist coupling	F: Critical buckling load (N/m)	G: Fatigue criterion
$0_2/+45/-45$	$3.78.10^{10}$	$8.89.10^9$	$2.45.10^5$	$2.45.10^5$	0	$6.14.10^4$	4.00

It should be noted that the since the value of the coupling coefficient is signed with no dimension, it is shown in absolute value in these diagrams, and with no normalization.

Examples 13 to 16:

The following table provides the main characteristics of different complexes where some of the layers are formed of different materials, for pairs of identical angles, that is, a 20° angle for the second layer and a -30° angle for the third layer, it being understood that the layer in the reference direction weighs twice as much as one or the other of the oriented layers of same material.

Example N°	Material of the 1 st layer	Material of the 2 nd layer	Material of the 3 rd layer	Conventional representation
13	Glass	Glass	Glass	$0_2/+20/-30$
14	Glass	Carbon	Glass	$0_2/+20C/-30$
15	Glass	Carbon	Carbon	$0_2/+20C/-30C$
16	Carbon	Glass	Glass	$0_2C/+20/-30$

The following table indicates the values of mechanical parameters for examples n°13 à 16.

Example N°	Conventional representation	A: Axial stiffness (Pa)	B: Shear stiffness (Pa)	C: Positive shear strength (Pa)	D : Negative shear strength (Pa)	E: Bend/twist coupling	F: Critical buckling load (N/m)	G: Fatigue criterion
13	0 ₂ /+20/-30	4.14.10 ¹⁰	6.79.10 ⁹	3.82.10 ⁵	5.09.10 ⁵	1.23.10 ⁻²	5.28.10 ⁴	5.10
14	0 ₂ /+20C/-45	5.24.10 ¹⁰	8.53.10 ⁹	7.02.10 ⁵	4.54.10 ⁵	-6.32.10 ⁻¹	6.49.10 ⁴	5.09
15	0 ₂ /+20C/-30C	6.22.10 ¹⁰	1.28.10 ⁹	6.43.10 ⁵	7.46.10 ⁵	-7.92.10 ⁻²	8.60.10 ⁴	5.07
16	0 ₂ C/+20/-30	8.58.10 ¹⁰	6.79.10 ⁹	5.56.10 ⁵	1.05.10 ⁶	1.01.10 ⁻²	5.95.10 ⁴	5.49

Figures 7A to 7D are 4 diagrams where each of the criteria of the above table are shown for each concerned example, after having been normalized in the same way as for examples 1 to 12.

Examples 17 to 21

The following table indicates the composition of complexes for 5 additional examples, where each of the layers is formed of glass yarns, for pairs of identical angles θ_1 θ_2 , of +20° for the second layer and -30° for the third layer, for which the masses per unit area of each of the layers are variable. The masses of the different layers are given in multiples of elementary masses per unit area for layers of a 0.125-mm thickness.

Example N°	Mass of the 1 st layer	Mass of the 2 nd layer	Mass of the 3 rd layer	Conventional representation
17	2	1	1	0 ₂ /+20/-30
18	1	1	1	0/+20/-30
19	2	2	1	0 ₂ /+20 ₂ /-30
20	2	2	2	0 ₂ /+20 ₂ /-30 ₂
21	2	1	2	0 ₂ /+20/-30 ₂

The following table indicates the values of mechanical parameters for examples n°17 to 21.

Example N°	Conventional representation	A: Axial stiffness (Pa)	B: Shear stiffness (Pa)	C: Positive shear strength (Pa)	D : Negative shear strength (Pa)	E: Bend/twist coupling	F: Critical buckling load (N/m)	G: Fatigue criterion
17	0 ₂ /+20/-30	4.14.10 ¹⁰	6.79.10 ⁹	3.82.10 ⁵	5.09.10 ⁵	1.23.10 ⁻²	5.28.10 ⁴	5.10
18	0/+20/-30	3.83.10 ¹⁰	7.69.10 ⁹	2.91.10 ⁵	3.72.10 ⁵	3.97.10 ⁻³	4.27.10 ⁴	4.96
19	0 ₂ /+20 ₂ /-30	4.01.10 ¹⁰	6.98.10 ⁹	5.89.10 ⁵	5.17.10 ⁵	-2.92.10 ⁻¹	6.70.10 ⁴	5.05
20	0 ₂ /+20 ₂ /-30 ₂	3.83.10 ¹⁰	7.69.10 ⁹	5.81.10 ⁵	7.44.10 ⁵	3.97.10 ⁻³	8.55.10 ⁴	4.96
21	0 ₂ /+20/-30 ₂	3.77.10 ¹⁰	7.37.10 ⁹	3.87.10 ⁵	7.12.10 ⁵	2.87.10 ⁻¹	7.13.10 ⁴	4.93

Figures 8A to 8E are 5 diagrams where each of the criteria of the above table are shown for each concerned example, after having been normalized in the same way as for examples 1 to 12.

Examples 22 to 26_{<0>}

The following table indicates the composition of complexes for 5 additional examples, where each of the layers is formed of glass fibers, for pairs of identical angles θ_1 θ_2 for the second layer and for the third layer, for which the materials of each of the layers are variable.

Example N°	Material of the 1 st layer	Material of the 2 nd layer	Material of the 3 rd layer	Conventional representation
22	Glass	Glass	Glass	0 ₂ /+30/-30
23	Glass	Carbon	Glass	0 ₂ /+25C/-25
24	Carbon	Carbon	Glass	0 ₂ C/+25C/-25
25	Glass	Carbon	Glass	0 ₂ /+30C/-30
26	Carbon	Carbon	Glass	0 ₂ C/+30C/-30

The following table indicates the values of mechanical parameters for examples n°22 to 26.

Example N°	Conventional representation	A: Axial stiffness (Pa)	B: Shear stiffness (Pa)	C: Positive shear strength (Pa)	D : Negative shear strength (Pa)	E: Bend/twist coupling	F: Critical buckling load (N/m)	G: Fatigue criterion
22	0 ₂ /+30/-30	3.85.10 ¹⁰	7.67.10 ⁹	3.91.10 ⁵	3.91.10 ⁵	0	5.71.10 ⁴	4.96
23	0 ₂ /+25C/-25	4.91.10 ¹⁰	9.23.10 ⁹	7.60.10 ⁵	4.15.10 ⁵	-5.82.10 ⁻¹	6.90.10 ⁴	5.09
24	0 ₂ C/+25C/-25	9.34.10 ¹⁰	9.52.10 ⁹	1.09.10 ⁶	6.57.10 ⁵	-5.78.10 ⁻¹	7.56.10 ⁴	5.72
25	0 ₂ /+30C/-30	4.34.10 ¹⁰	1.07.10 ¹⁰	5.56.10 ⁵	3.80.10 ⁵	-4.55.10 ⁻¹	7.82.10 ⁴	4.94
26	0 ₂ C/+30C/-30	8.77.10 ¹⁰	1.10.10 ¹⁰	9.11.10 ⁵	6.57.10 ⁵	-4.50.10 ⁻¹	8.49.10 ⁴	5.94

Figures 9A to 9E are 5 diagrams in which each of the criteria of the above table are shown for each concerned example, after having been normalized in the same way as for examples 1 to 12.

Examples 27 to 32

The following table indicates the composition of complexes for 6 additional examples, where each of the layers is formed of glass yarns, for pairs of identical angles $\theta_1 \theta_2$ of +20° or +30° for the oriented layers, for which the masses per unit area of each of the layers are variable. The masses of the different layers are given in multiples of elementary masses per unit area, for a layer of a 0.125-mm thickness.

Example N°	Mass of the 1 st layer	Mass of the 2 nd layer	Mass of the 3 rd layer	Conventional representation
27	2	1	1	0 ₂ /+25/-25
28	2	2	1	0 ₂ /+25 ₂ /-25
29	1	1	1	0/+25/-25
30	2	1	1	0 ₂ /+30/-30
31	2	2	1	0 ₂ /+30 ₂ /-30
32	1	1	1	0 ₂ /+30/-30

The following table indicates the values of mechanical parameters for examples n°27 to 32.

Example N°	Conventional representation	A: Axial stiffness (Pa)	B: Shear stiffness (Pa)	C: Positive shear strength (Pa)	D : Negative shear strength (Pa)	E: Bend/twist coupling	F: Critical buckling load (N/m)	G: Fatigue criterion
27	0 ₂ /+25/-25	4.14.10 ¹⁰	6.87.10 ⁹	4.47.10 ⁵	4.47.10 ⁵	0	5.26.10 ⁴	5.11
28	0 ₂ /+25 ₂ /-25	3.89.10 ¹⁰	7.27.10 ⁹	6.63.10 ⁵	4.50.10 ⁵	-3.00.10 ⁻¹	6.88.10 ⁴	4.99
29	0/+25/-25	3.83.10 ¹⁰	7.83.10 ⁹	3.30.10 ⁵	3.30.10 ⁵	0	4.25.10 ⁴	4.96
30	0 ₂ /+30/-30	3.85.10 ¹⁰	7.67.10 ⁹	3.91.10 ⁵	3.91.10 ⁵	0	5.71.10 ⁴	4.96
31	0 ₂ /+30 ₂ /-30	3.54.10 ¹⁰	8.19.10 ⁹	5.37.10 ⁵	4.01.10 ⁵	-2.51.10 ⁻¹	7.53.10 ⁴	4.76
32	0/+30/-30	3.42.10 ¹⁰	8.89.10 ⁹	2.76.10 ⁵	2.76.10 ⁵	0	4.61.10 ⁴	4.67

Figures 10A to 10F are 6 diagrams in which each of the criteria of the above table are shown for each concerned example, after having been normalized in the same way as for examples 1 to 12.

INDUSTRIAL APPLICATIONS

The present invention finds multiples applications in the field of high-performance composite materials, and especially in aeronautics, wind generator construction, and automobile, without this being a limiting list. Due to the specific structure of the associated layers, the present invention enables to optimize various mechanical parameters of composite parts, by privileging certain critical factors for certain applications, while maintaining the other factors at satisfactory levels.

Thus, in the specific application to wind generator blades, the axial stiffness may be a particularly appreciated factor to limit flexural deflections of wind generator blades. Indeed, the blades are submitted to stress in the rotation planes, that is, perpendicularly to the rotation axis of the helix, and in particular to stress due to their own weight. The blade must also withstand stress perpendicular to this rotation plane, in particular stress due to the wind pressure.

The shear stiffness also is an important factor for the construction of wind generator blades since the blades are submitted to twisting strain mainly caused by stress due to wind, as well as to the blade inclination which influences the pitch angle, as well as to the very weight of the blade. Positive and negative strengths are also important for the design of a wind generator blade since it is a rotating structure, where the direction of the stress applied to a portion of the blade reverses according to the angular position of the helix.

Similarly, wind generator blades are particularly elongated and flexible structures, so that it is useful for them to have a good resistance to buckling.

The present invention enables to provide a coupling between bending and twisting phenomena, with the advantage that a wind generator blade passively modifies the pitch angle of the blade without requiring any complex mechanism. The adjustment of the pitch angle thus enables to decrease the value of the maximum load applied to the blade, and accordingly contributes to decreasing the fatigue of the material and of the different junction portions between the blades and the supporting structure. Indeed, by analogy with experimentations carried out on prior art installations, by analysis of the S-N curves (stress-number of cycles), it can be estimated that a decrease on the order of 10% of the maximum load applied to the blade results in an increase by a factor on the order of ten on the number of cycles before failure. An increase of the blade performance and a lengthening of the lifetime have also been observed. It is indeed considered that a wind generator blade must have a lifetime of approximately twenty years, substantially corresponding to 200,000,000 rotations, and the design according to the present invention enables to relieve structures, thus increasing the lifetime.

CLAIMS

1/ A reinforcing textile complex (1) for a composite part, comprising several layers (2, 3, 4) of high-tenacity yarns, said yarns being arranged in parallel fashion within each layer, with no crimp, that is:

- a first layer (2) having its yarns (6) oriented along a reference direction (7);
- a second layer (3) having its yarns (8) oriented along a direction (9) forming a first non-zero angle (θ_1) with the reference direction (7);
- a third layer (4) having its yarns (10) oriented along a direction (11) forming a second angle (θ_2) with the reference direction (7), said first and second angles being of opposite directions, and having an absolute value less than 60° ,

the layers being assembled by sawing, knitting or gluing, **characterized in that** the second and the third layers differ by at least one parameter selected from the group comprising:

- the absolute value of the angle of the direction of the yarns with respect to the reference direction,
- the mass per unit area,
- the material forming the yarns of said layers.

2/ The textile complex of claim 1, wherein the difference between the absolute values of the angles (θ_1 , θ_2) of the directions of the second and third layers is greater than 5° .

3/ The textile complex of claim 2, characterized in that the direction (9) of the yarns of the second layer forms an angle (θ_1) ranging between 10° and 35° with the reference direction (7).

4/ The textile complex of claim 2, **characterized in that** the direction (11) of the yarns (10) of the third layer forms an angle (θ_2) ranging between -60° and -25° with the reference direction (7).

5/ The textile complex of claim 1, **characterized in that** the high-tenacity yarns are formed from a material selected from the group comprising carbon, glass, aramide, and basalt.

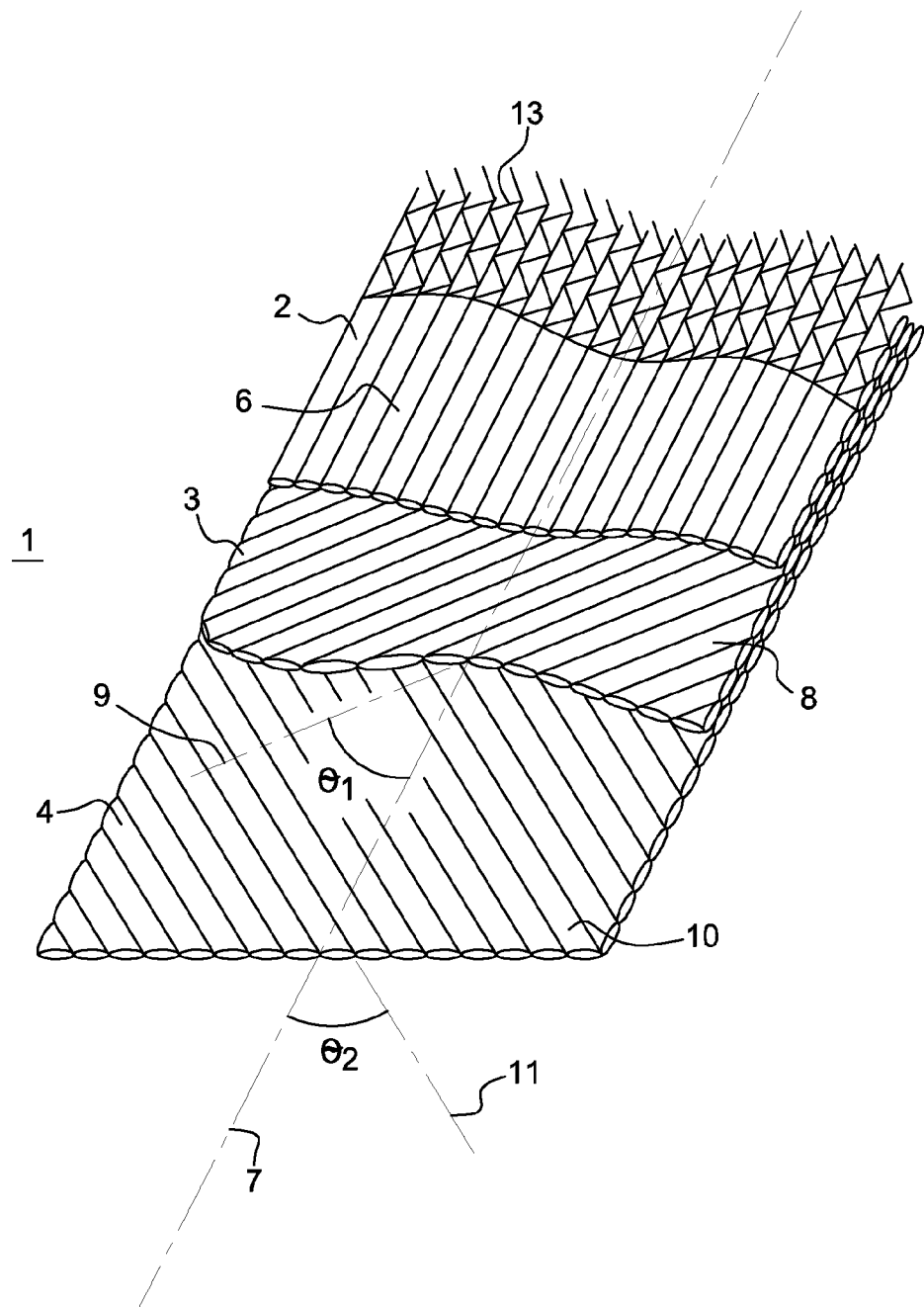
6/ The textile complex of claim 1, **characterized in that** the yarns (10) of the third layer (4) are based on a material different from the material of the yarns (8) of the second layer (3).

7/ The textile complex of claim 4, **characterized in that** the masses per unit area of the second and third layers differ by more than 10 %.

8/ A stack of several textile complexes of any of the foregoing claims, wherein the first layers of all complexes are oriented along a common direction.

9/ A use of the textile complex of any of claims 1 to 7 or of the stack of claim 8 for the manufacturing of a wind generator blade.

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**Fig. 1**

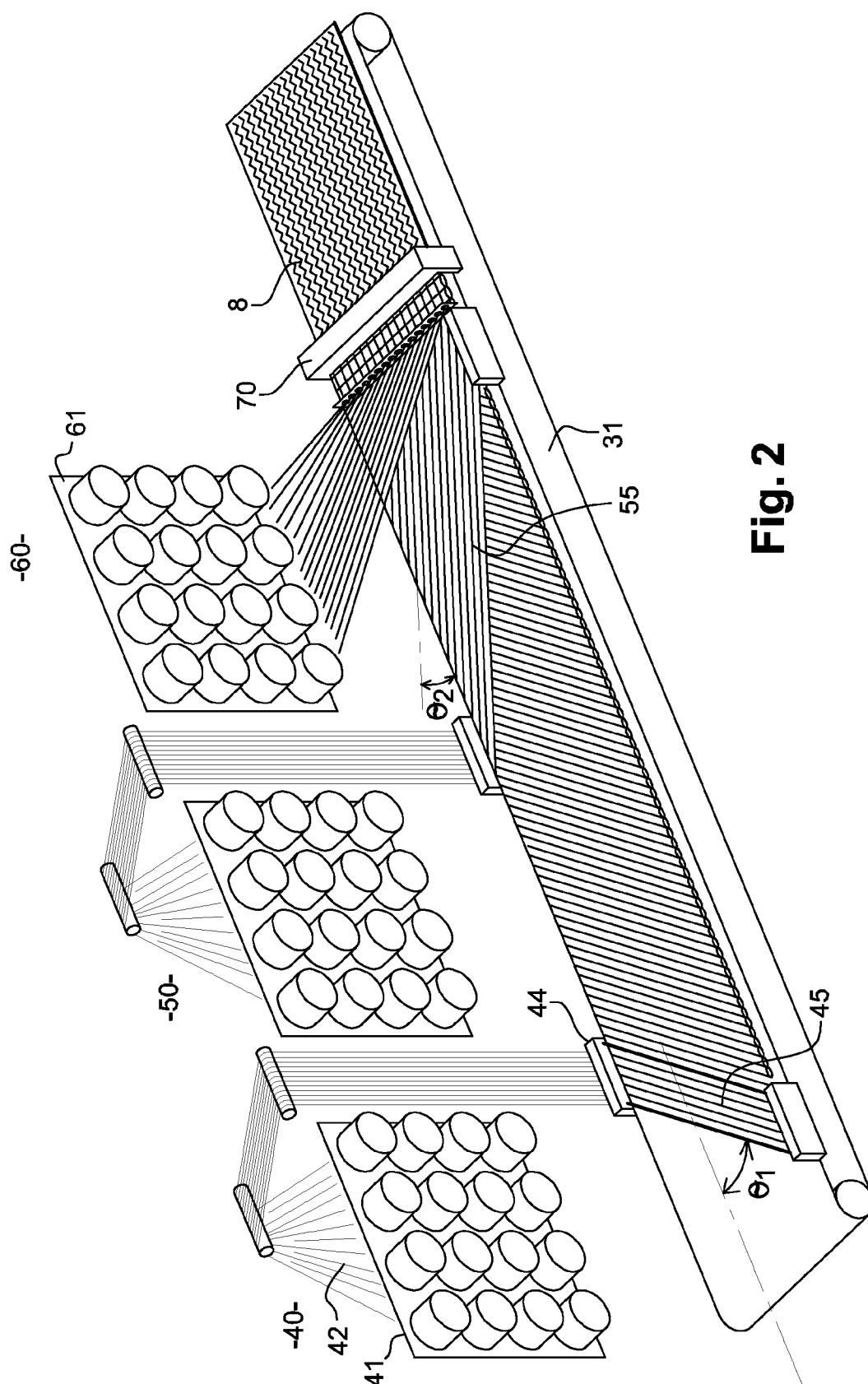
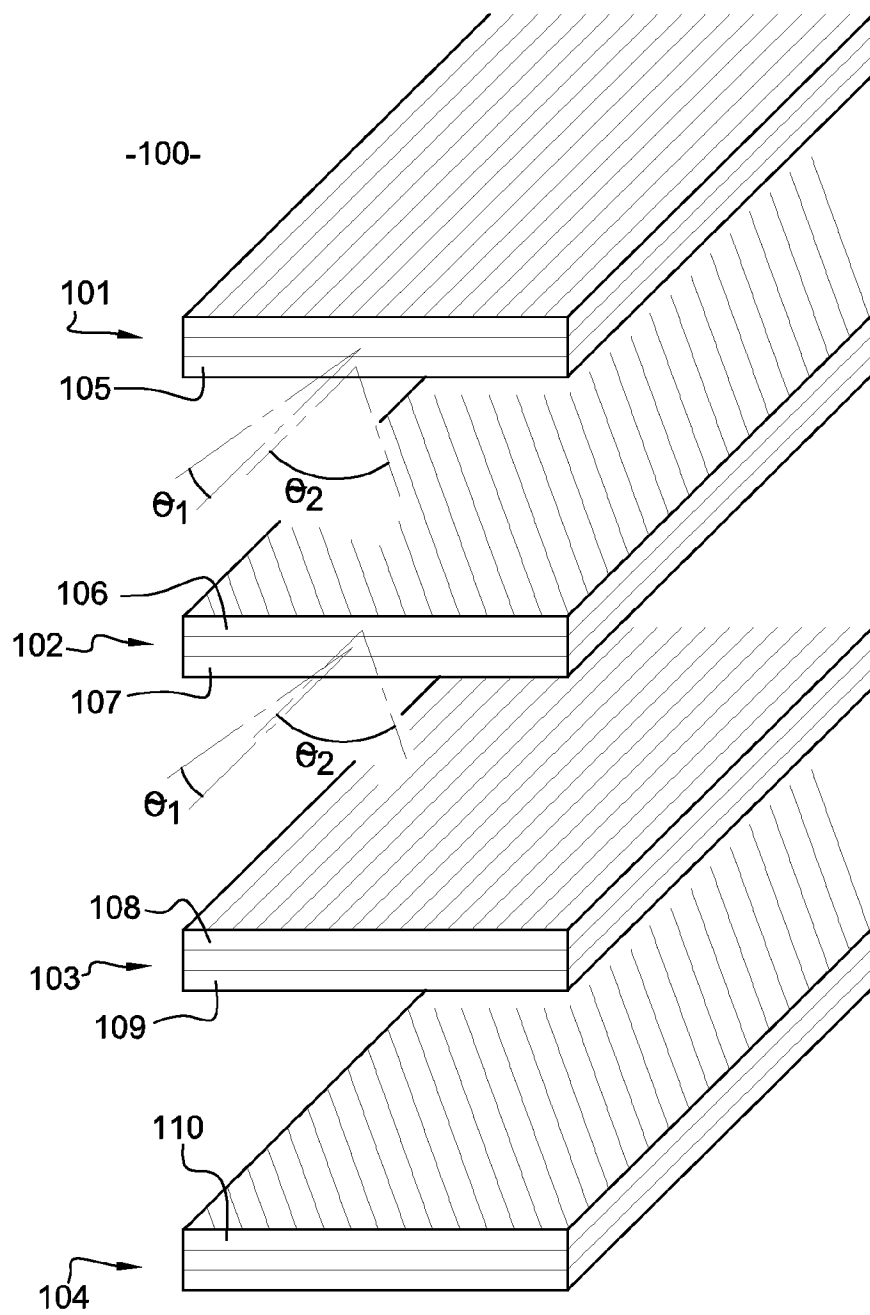


Fig. 2

**Fig. 3**

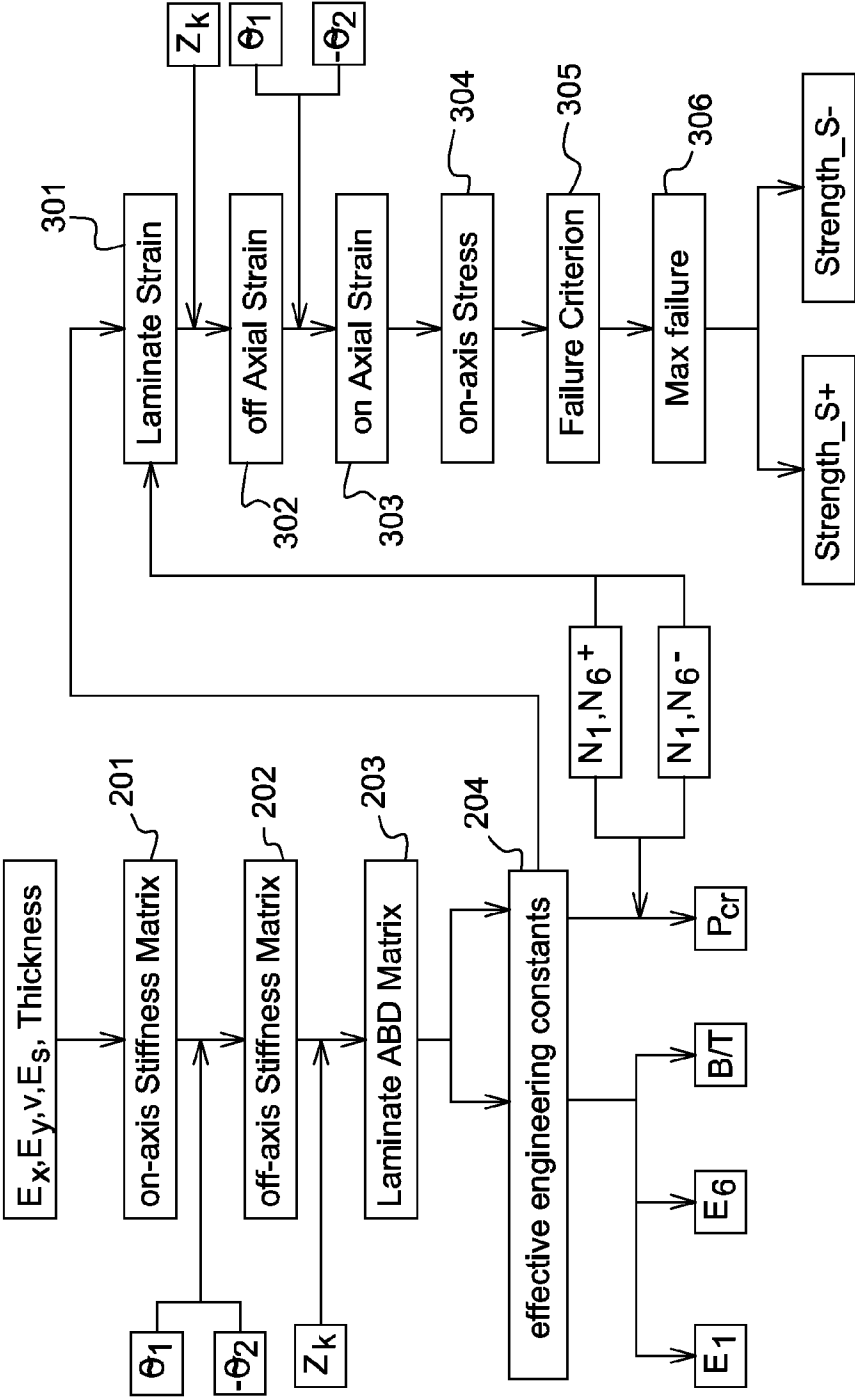


Fig. 4

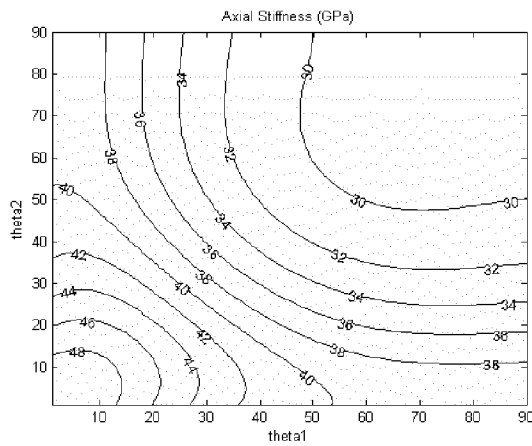


Fig. 5A

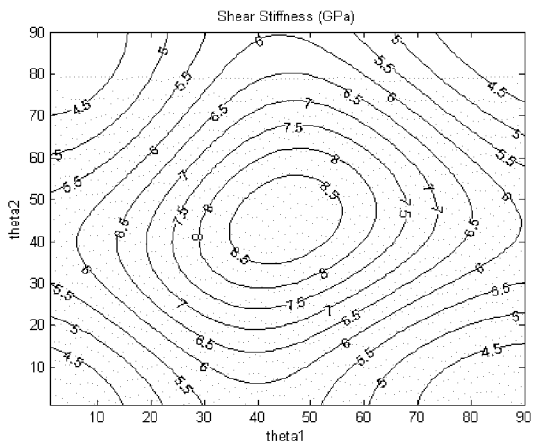


Fig. 5B

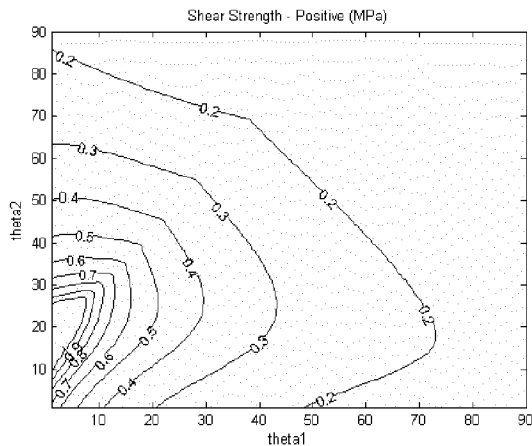


Fig. 5C

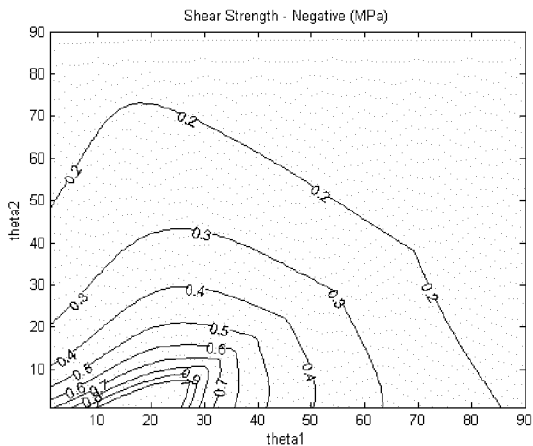


Fig. 5D

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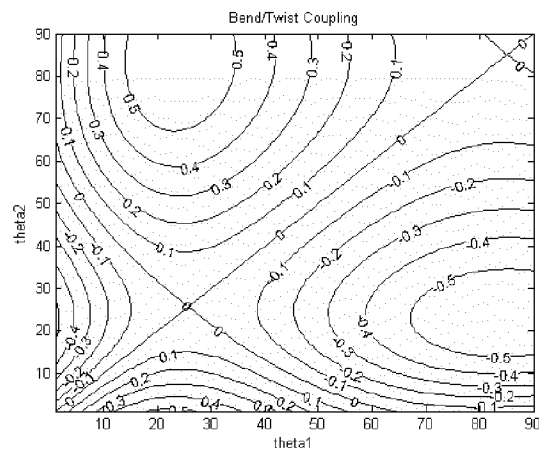


Fig. 5E

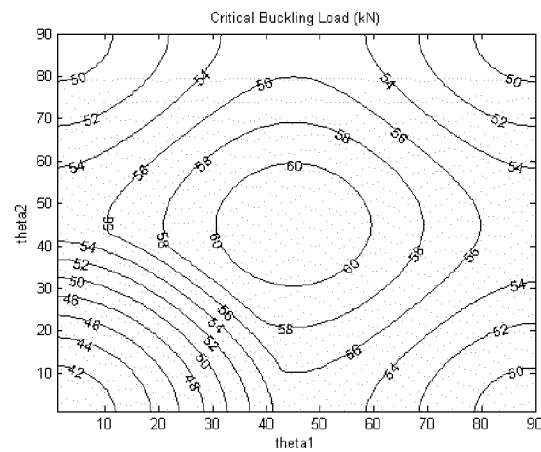


Fig. 5F

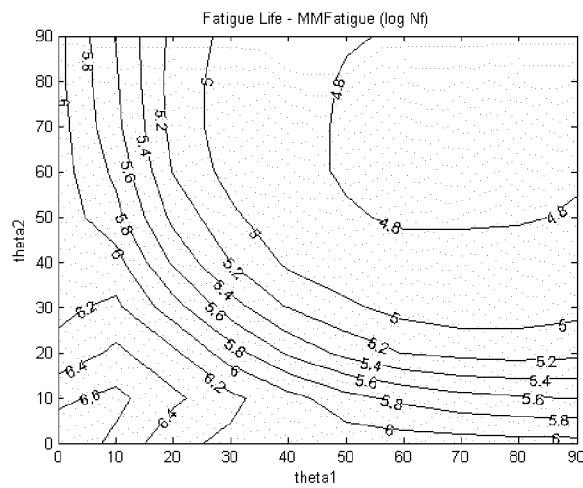
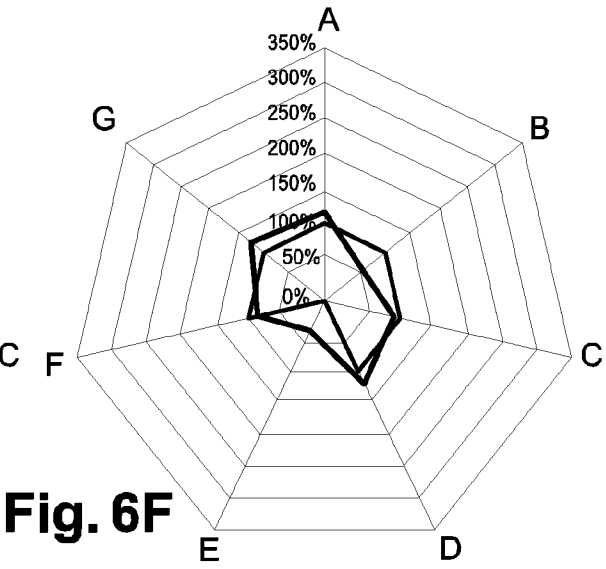
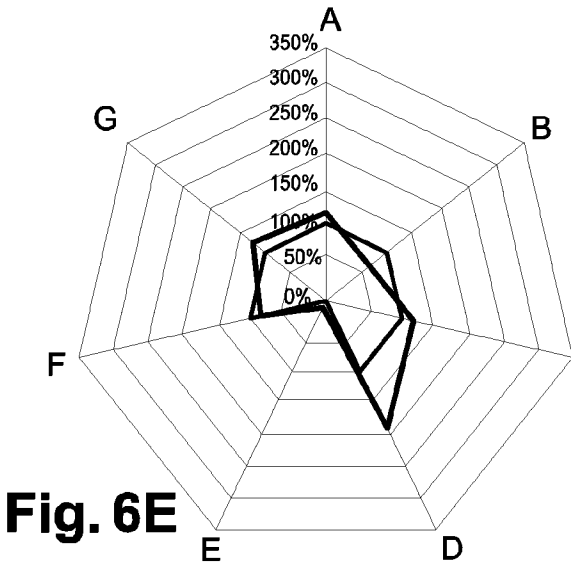
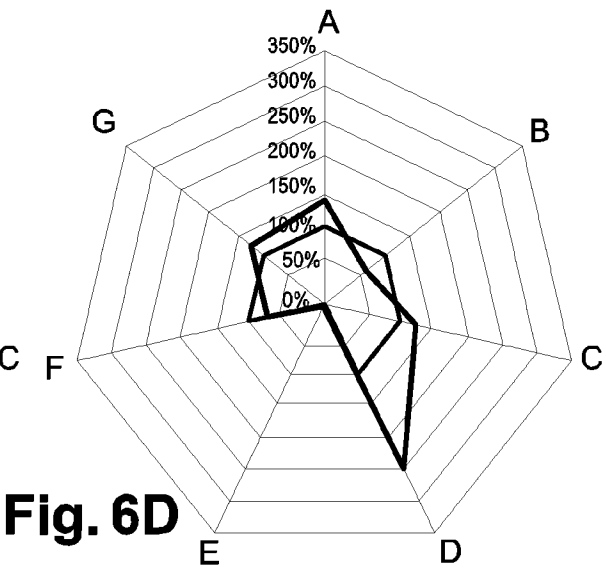
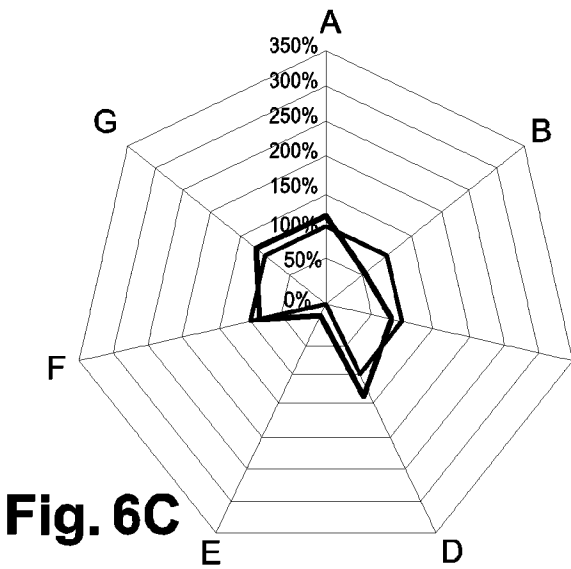
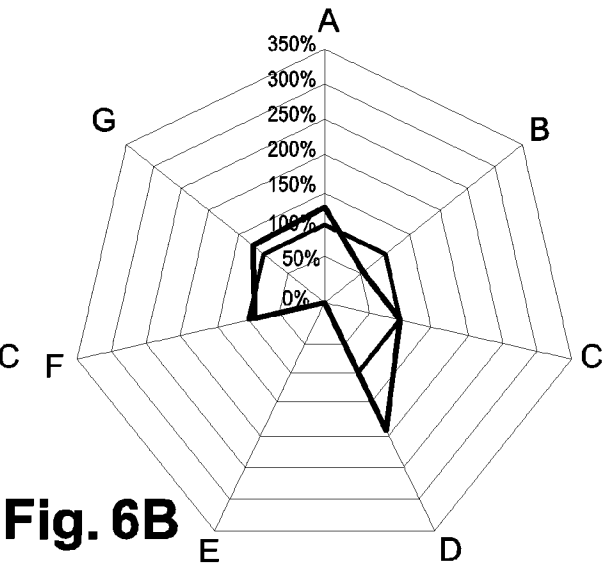
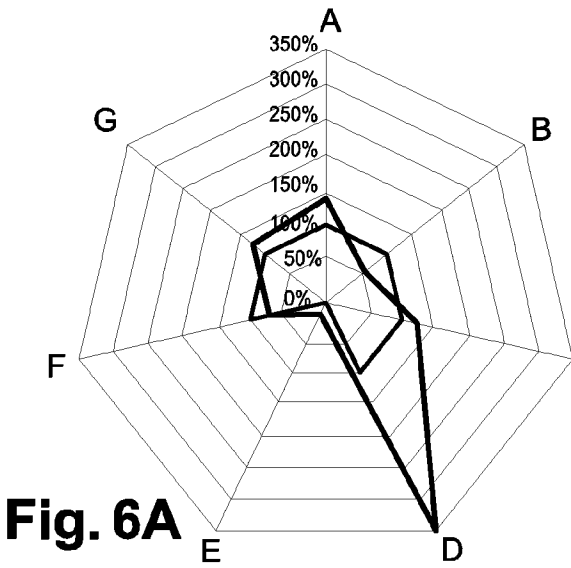
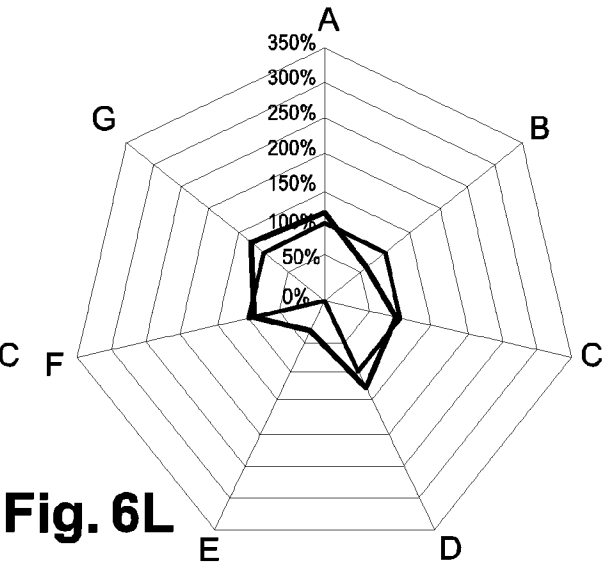
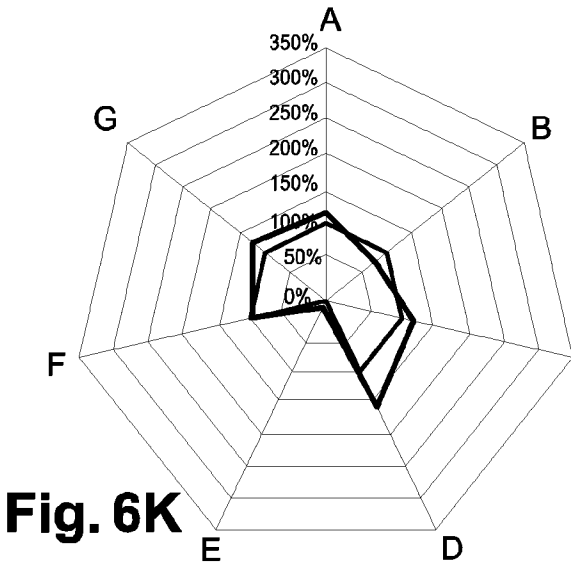
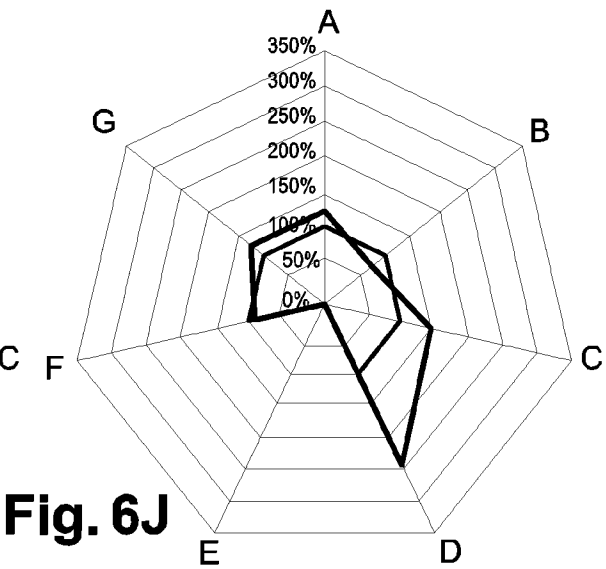
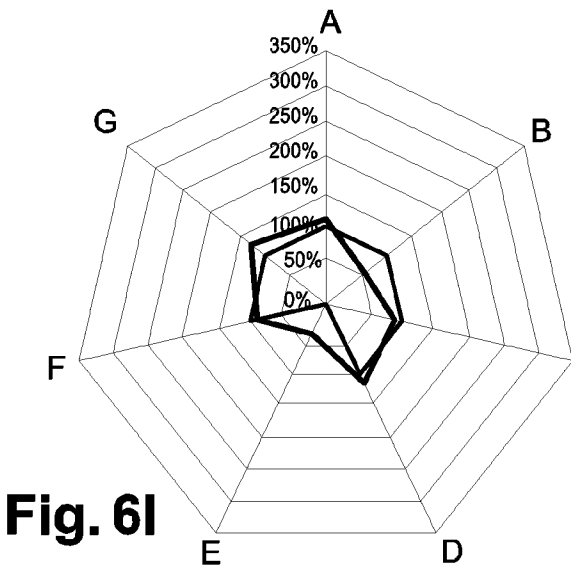
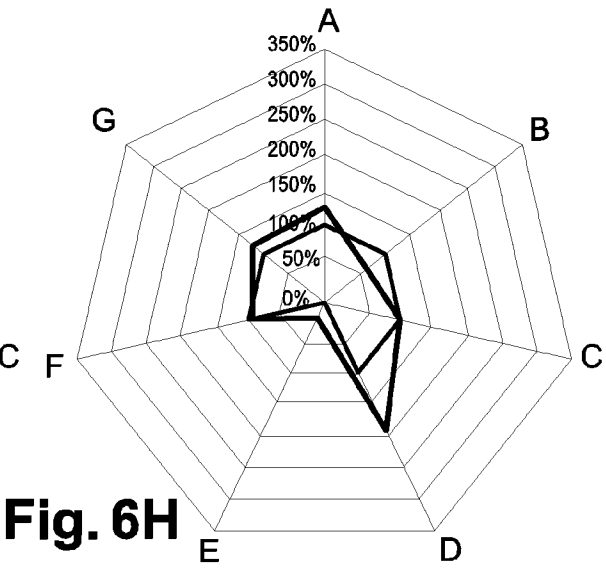
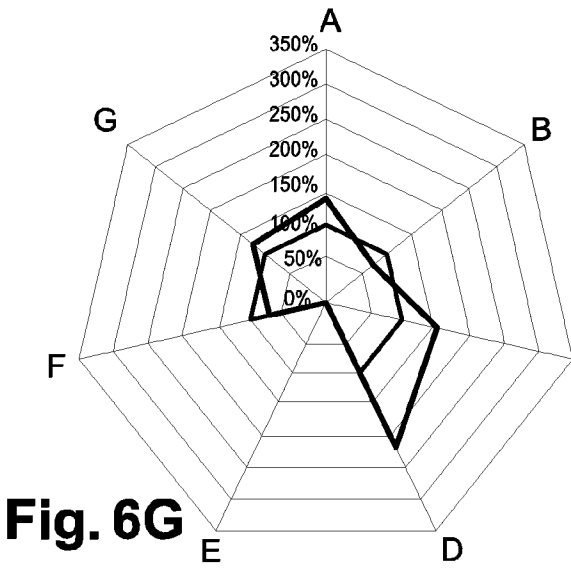


Fig. 5G





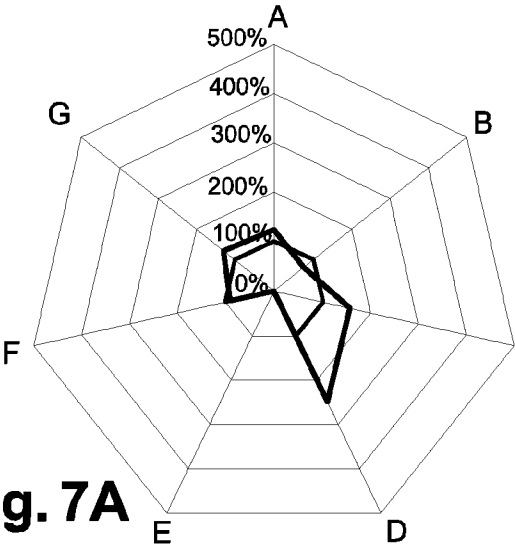


Fig. 7A

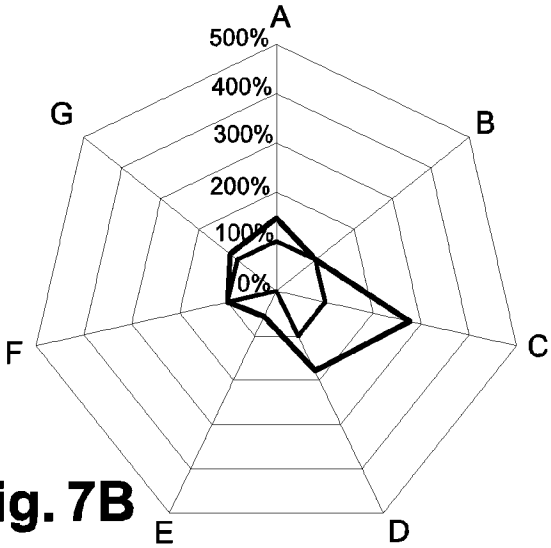


Fig. 7B

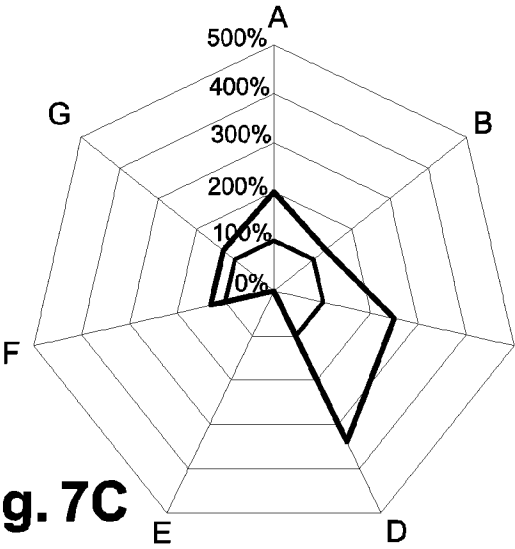


Fig. 7C

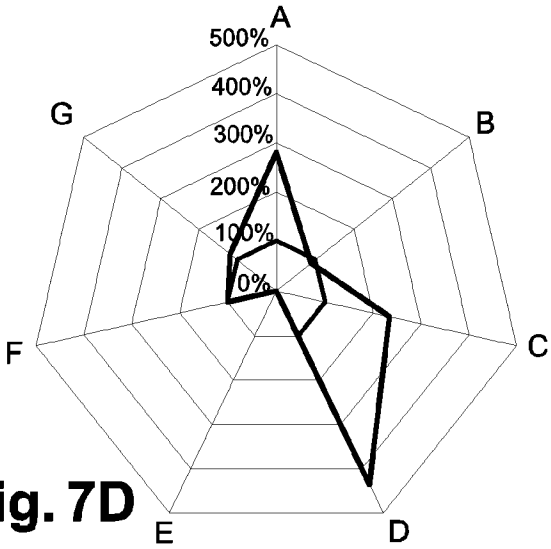


Fig. 7D

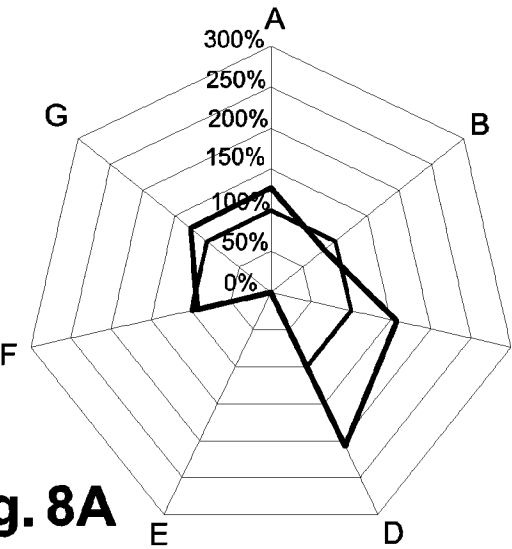


Fig. 8A

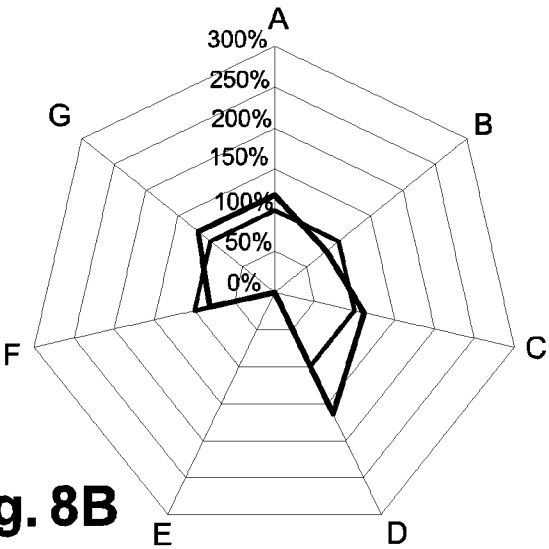


Fig. 8B

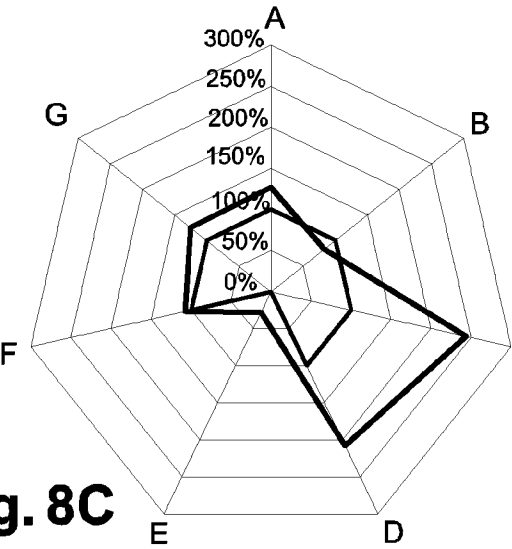


Fig. 8C

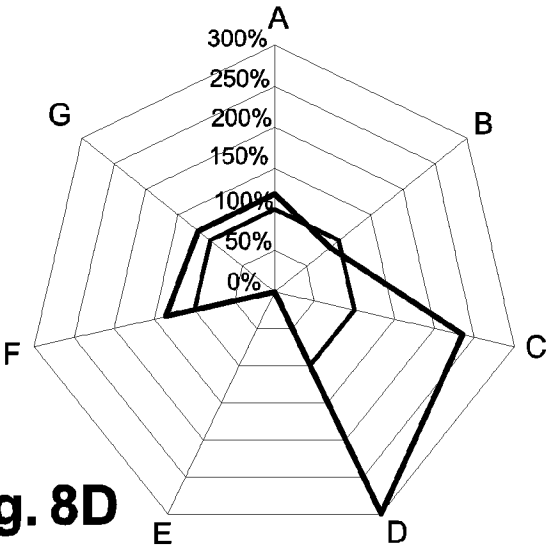


Fig. 8D

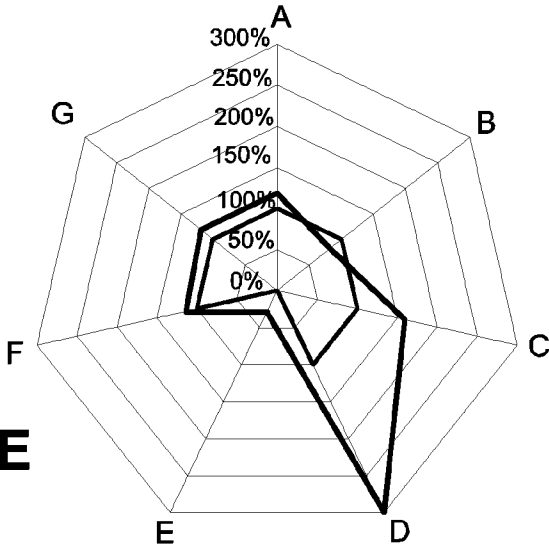


Fig. 8E

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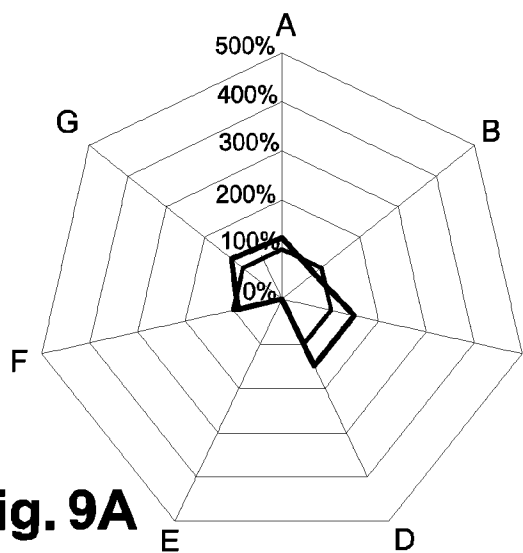


Fig. 9A

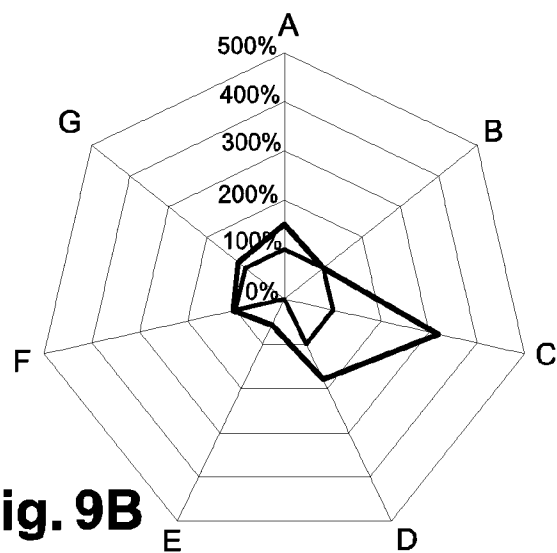


Fig. 9B

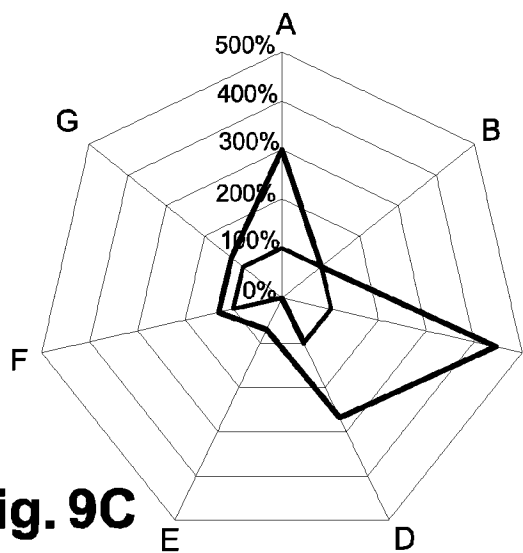


Fig. 9C

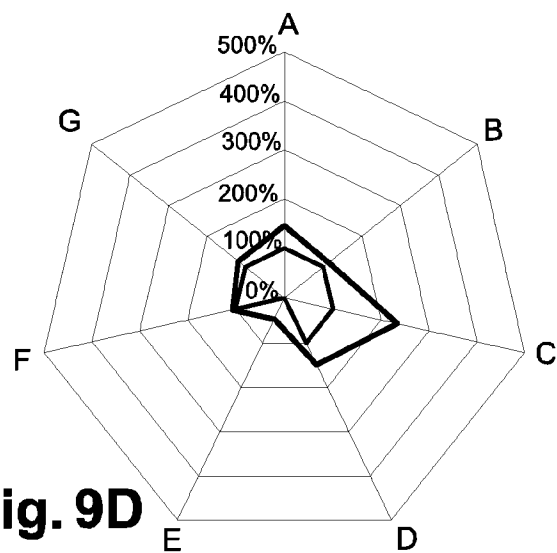


Fig. 9D

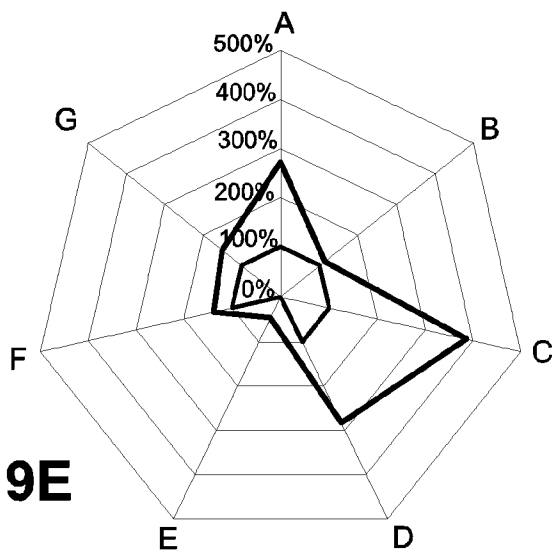


Fig. 9E

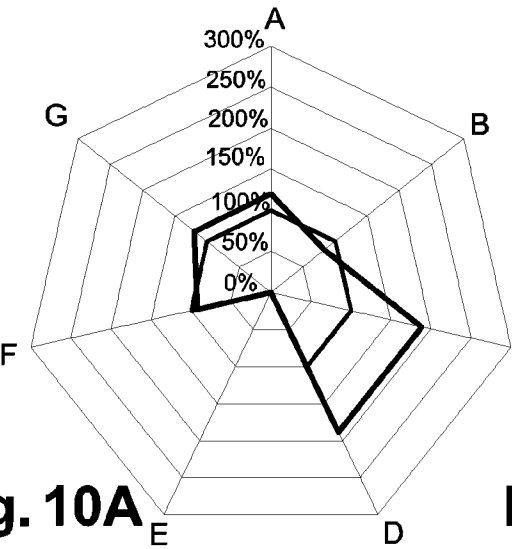


Fig. 10A

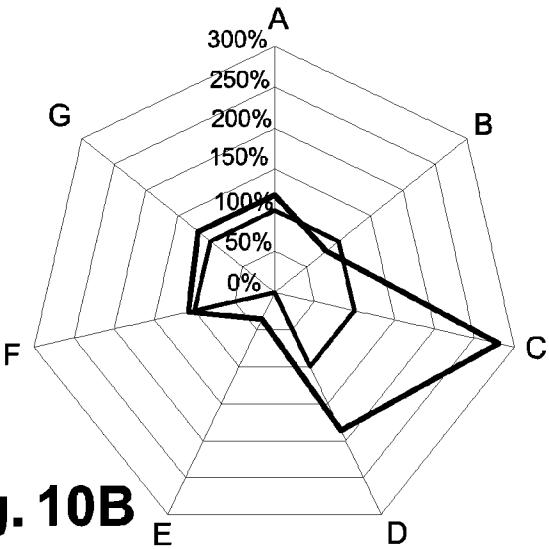


Fig. 10B

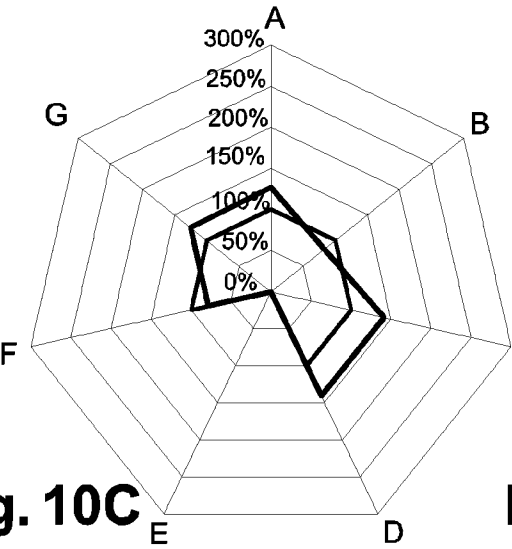


Fig. 10C

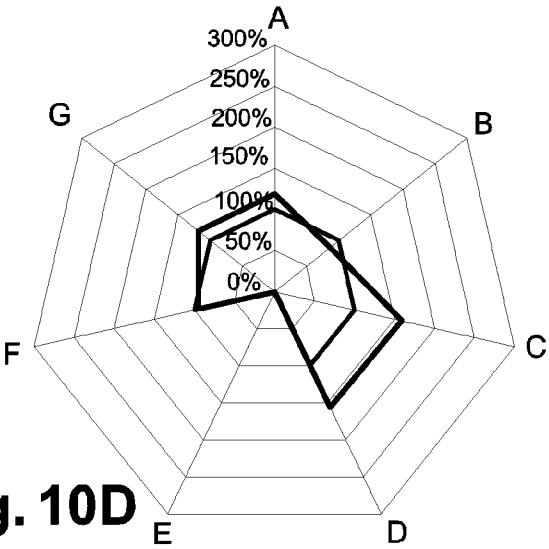


Fig. 10D

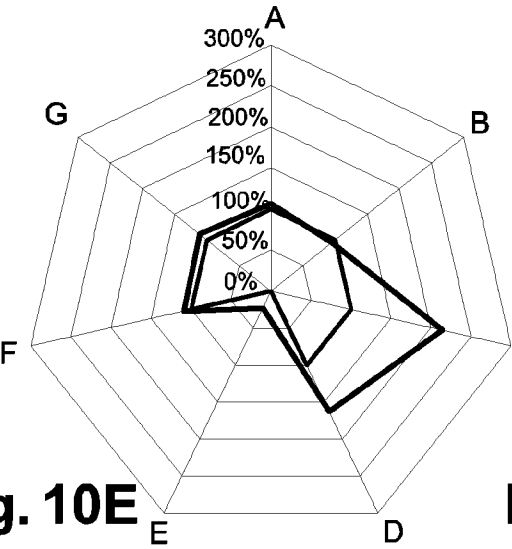


Fig. 10E

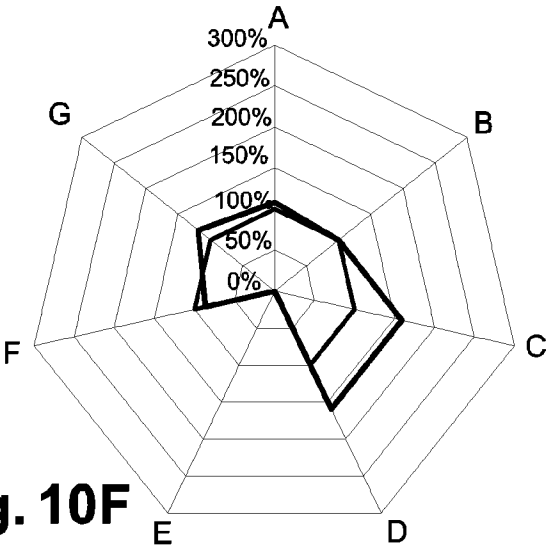


Fig. 10F

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2013/064388

A. CLASSIFICATION OF SUBJECT MATTER

INV. D04B21/16

ADD. B29C70/24

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)

D04B B29C

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 practicable, search terms used)

EP0-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	column 2, line 29 - column 5, line 23;	9
A	claims 8-10; figures 7, 8, 10, 12 -----	6
X	WO 98/10128 A1 (MC DONNELL DOUGLAS CORP [US]; WAGENER GERT [DE]; PALMER RAYMOND J [US]) 12 March 1998 (1998-03-12)	1-8
Y	page 16, line 8 - page 36, line 12; claims 14, 18, 20, 37; figures 2-8 -----	9
X	WO 96/10666 A1 (LOCKHEED CORP [US]) 11 April 1996 (1996-04-11) page 4, line 29 - page 6, line 31; claims 3, 7-10; figures 4-6 page 7, line 30 - page 8, line 26 ----- -/-	1,2,5,6



Further documents are listed in the continuation of Box C.



See patent family annex.

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/064388

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