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**Datasheet for the decision  
of 12 March 2014**

**Case Number:** T 0154/13 - 3.5.07  
**Application Number:** 02797880.8  
**Publication Number:** 1434150  
**IPC:** G06F17/50  
**Language of the proceedings:** EN

**Title of invention:**

Three-dimensional mesh generating method, magnetic field analysis method for rotating machine, three-dimensional mesh generating device, magnetic field analysis device for rotating machine, computer program, and recording medium

**Applicant:**

JSOL Corporation

**Headword:**

Finite element method for skewed rotor/JSOL

**Relevant legal provisions:**

EPC Art. 56

**Keyword:**

Inventive step - (no) (all requests)

**Decisions cited:**

**Catchword:**



**Beschwerdekammern  
Boards of Appeal  
Chambres de recours**

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Case Number: T 0154/13 - 3.5.07

**D E C I S I O N**  
**of Technical Board of Appeal 3.5.07**  
**of 12 March 2014**

**Appellant:** JSOL Corporation  
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**Decision under appeal:** **Decision of the Examining Division of the  
European Patent Office posted on 24 August 2012  
refusing European patent application No.  
02797880.8 pursuant to Article 97(2) EPC.**

**Composition of the Board:**

**Chairman:** R. Moufang  
**Members:** M. Rognoni  
P. San-Bento Furtado

## Summary of Facts and Submissions

I. The applicant (appellant) appealed against the decision of the examining division to refuse European patent application no. 02797880.8.

II. In the decision under appeal, the examining division held, *inter alia*, that the subject-matter of claim 1, filed with letter dated 19 June 2007, did not involve an inventive step, having regard to the following documents:

D1: D. Rodger *et al.*: "Coupled elements for problems involving movement", IEEE Transactions on Magnetics, vol. 26, no. 2, March 1990, pages 548 - 550;

D2: Haruyuki Kometani *et al.*: "3-D Analysis of Induction Motor with Skewed Slots Using Regular Coupling Mesh", IEEE Transactions on Magnetics, vol. 36, no. 4, July 2000, pages 1769 - 1773.

III. The appellant requested that the decision under appeal be set aside and that a patent be granted on the basis of the main request or of the auxiliary request 1 filed with the statement of grounds of appeal.

IV. In a communication dated 26 November 2013 summoning the appellant to oral proceedings, the Board drew the appellant's attention to the following document identified in the contested decision:

D4: S.L. Ho *et al.*: "*Generation and Rotation of 3-D Finite Element Mesh for Skewed Rotor Induction Motors Using Extrusion Technique*", IEEE

Transactions on Magnetism vol. 35, no. 3, May 1999, pages 1266 - 1269.

Furthermore, the following prior art was introduced into the appeal proceedings:

D6: EP-A-1 081 657

D7: US-B-6 259 453.

According to the Board's provisional opinion, the subject-matter of claims 1 of the main request and of the auxiliary request 1 did not involve an inventive step within the meaning of Article 56 EPC.

- V. In response to the Board's communication, the appellant requested with letter dated 12 December 2013 to conduct the oral proceedings as a videoconference.
- VI. Before being informed that it would not be allowed to conduct oral proceedings as a videoconference, the appellant, with letter dated 10 January 2014, withdrew the request for a videoconference and informed the Board that it had decided not to attend the oral proceedings.
- VII. Oral proceedings were held as scheduled on 12 March 2014 in the absence of the appellant.
- VIII. Claim 1 according to the main request reads as follows:

"A method for generating a three-dimensional mesh representing a rotating machine that includes a stator, a rotor rotating around a rotation axis, and a spatial area among the stator and the rotor, either or both of the stator and the rotor having a skew configured with

a twisted structure in a direction of the rotation axis of the rotor, by a combination of a plurality of polyhedrons, comprising the steps of:

generating a two-dimensional mesh for a plane of the rotating machine perpendicular to the rotation axis, which includes polygons for the rotor and polygons for the stator;

generating another two-dimensional mesh for another plane of the rotating machine perpendicular to the rotation axis, based on the twisted structure;

generating an initial three-dimensional mesh for a solid of the rotating machine by stacking a plurality of the two-dimensional meshes, in accordance with the direction of the rotation axis, which includes polyhedrons for the rotor and polyhedrons for the stator;

filling a space among the polyhedrons for the rotor and the stator of the generated initial three-dimensional mesh with tetrahedrons and a quadrangular pyramid, to generate the three-dimensional mesh."

Claim 4 reads as follows:

"A method for generating a three dimensional mesh representing a rotating machine that includes a stator, a rotor rotating around a rotation axis and a spatial area among the stator and the rotor, either or both of the stator and the rotor having a skew configured with a twisted structure in a direction of the rotation axis of the rotor, by a combination of a plurality of polyhedrons by a computer, comprising the steps of:

receiving from an input unit and storing into a storage unit an initial three dimensional mesh for a solid of the rotating machine which mesh is stacked of a plurality of two-dimensional meshes for respective planes of the rotating machine perpendicular to the rotation axis, each two-dimensional mesh including polygons for the rotor and polygons for the stator;

filling a space among the polyhedrons for the rotor and the stator of the generated initial three-dimensional mesh with tetrahedrons and a quadrangular pyramid, and storing them into the storage unit."

Claim 5 reads as follows:

"A method for analyzing a magnetic field of a rotating machine by a finite element method using a three-dimensional mesh representing the rotating machine, including a spatial area between a stator and a rotor, by a combination of a plurality of polyhedrons, comprising the steps of:

generating a three-dimensional mesh representing a rotating machine to be analyzed by using the three-dimensional mesh generating method of any one of claims 1 through 4, rotating a rotor side of the three-dimensional mesh, and analyzing the magnetic field by the finite element method."

Claim 6 reads as follows:

"An apparatus (1) for generating a three-dimensional mesh representing a rotating machine that includes a stator, a rotor rotating around a rotation axis and a spatial area among the stator and the rotor, either or both of the stator and the rotor having a skew

configured with a twisted structure in a direction of the rotation axis of the rotor, by a combination of a plurality of polyhedrons, comprising:

means for receiving an initial three-dimensional mesh for a solid of the rotating machine, which meshes [sic] is stacked of a plurality of two-dimensional meshes for respective planes of the rotating machine perpendicular to the rotation axis, each two-dimensional mesh including polygons for the rotor and polygons for the stator;

means for filling a space among the polyhedrons for the rotor and the stator of the generated initial three-dimensional mesh with tetrahedrons and a quadrangular pyramid."

Claim 7 reads as follows:

"An apparatus (4) for analyzing a magnetic field of a rotating machine by a finite element method using a three-dimensional mesh representing the rotating machine that includes a stator, a rotor rotating around a rotation axis and a spatial area among the stator and the rotor, either or both of the stator and the rotor having a skew configured with a twisted structure in a direction of the rotation axis of the rotor, by a combination of a plurality of polyhedrons, comprising:

means for generating a three-dimensional mesh representing a rotating machine to be analyzed, by using the three dimensional mesh generating apparatus of claim 6; and means for rotating the rotor side of three-dimensional mesh, and analyzing the magnetic field by the finite element method."

Claim 8 reads as follows:

"A computer program (20) for causing a computer to generate a three-dimensional mesh representing a rotating machine, that includes a stator, a rotor rotating around a rotation axis and a spatial area among the stator and the rotor, either or both of the stator and the rotor having a skew configured with a twisted structure in a direction of the rotation axis of the rotor, by a combination of a plurality of polyhedrons, by using an initial three-dimensional mesh for a solid rotating machine which mesh is stacked of a plurality of two-dimensional meshes for respective planes of the rotating machine perpendicular to the rotation axis, each two-dimensional mesh including polygons for the rotor and polygons for the stator, comprising the step of:

causing the computer to fill a space among the polyhedrons for the rotor and the stator of the generated initial three-dimensional mesh with tetrahedrons and a quadrangular pyramid."

Claim 9 reads as follows:

"A computer program (50) for causing a computer to analyze a magnetic field of a rotating machine by a finite element method using a three-dimensional mesh representing a rotating machine, that includes a stator, a rotor rotating around a rotation axis and a spatial area among the stator and the rotor, either or both of the stator and the rotor having a skew configured with a twisted structure in a direction of the rotation axis of the rotor, by a combination of a plurality of polyhedrons, comprising the steps of:



causing the computer to generate a three-dimensional mesh representing a rotating machine to be analyzed, by using the computer program of claim 8; and causing the computer to rotate a rotor side of the three-dimensional mesh and analyze the magnetic field by the finite element method."

Claim 10 reads as follows:

"A memory product (2) readable by a computer storing a computer program (20) for causing a computer to generate a three-dimensional mesh representing a rotating machine, that includes a stator, a rotor rotating around a rotation axis and a spatial area among the stator and the rotor, either or both of the stator and the rotor having a skew configured with a twisted structure in a direction of the rotation axis of the rotor, by a combination of a plurality of polyhedrons, by using an initial three-dimensional mesh for solid rotating machine which mesh is stacked of a plurality of two-dimensional meshes for respective planes of the rotating machine perpendicular to the rotation axis, each two-dimensional mesh including polygons for the rotor and polygons for the stator, the memory product (2) storing a computer program comprising the step of:

causing the computer to fill a space among the polyhedrons for the rotor and the stator of the generated initial three-dimensional mesh, with tetrahedrons and a quadrangular pyramid."

Claim 11 reads as follows:

"A memory product (5) readable by a computer storing a computer program (50) for causing a computer to analyze

a magnetic field of a rotating machine by a finite element method using a three-dimensional mesh representing a rotating machine, that includes a stator, a rotor rotating around a rotation axis and a spatial area among the stator and the rotor, either or both of the stator and the rotor having a skew configured with a twisted structure in a direction of the rotation axis of the rotor, by a combination of a plurality of polyhedrons, the memory product (5) storing a computer program, comprising the steps of:

causing the computer to generate a three-dimensional mesh representing a rotating machine to be analyzed, by using the computer program stored in the memory product of claim 10; and causing the computer to rotate a rotor side of the three-dimensional mesh and analyze the magnetic field by the finite element method."

Claim 1 according to the auxiliary request 1 reads as follows:

"A method for generating a three-dimensional mesh representing a rotating machine with a stator, a rotor rotating around a rotation axis, and a spatial area between the stator and the rotor, the rotor having a skew configured with a twisted structure in a direction of the rotation axis of the rotor, by a combination of a plurality of polyhedrons, comprising the steps in the following order of:

- a) generating a two-dimensional mesh in which a ring-shaped gap is provided around the rotation axis in the spatial area, portions facing each other with the ring-shaped gap therebetween are equally divided into mutually equal number of parts, and a stator-side portion and a rotor-side portion,

excluding the ring-shaped gap, are represented by a combination of a plurality of polyhedrons on a plane perpendicular to the rotation axis;

- b) generating an initial three-dimensional mesh by stacking a plurality of the two-dimensional meshes with the stator-side portion and the rotor-side portion relatively rotated on the rotation axis according to the twisted structure, in the direction of the rotation axis according to a same rule in the stator-side portion and the rotor-side portion;
- c) forming a boundary surface constructed by a mesh surface obtained by concentrically projecting, into a cylindrical gap composed of a stack of the ring-shaped gaps, any one of a stator-side mesh surface and a rotor-side mesh surface which face each other with the cylindrical gap therebetween;
- d) filling spaces between the boundary surface and the stator-side mesh surface and rotor-side mesh surface with a plurality of polyhedrons, including polyhedrons comprising each of surface elements constituting the boundary surface, the stator-side mesh surface and the rotor-side mesh surface as one face, to generate the three-dimensional mesh,

wherein the two-dimensional mesh is composed of a combination of a plurality of quadrangles, and

wherein the initial three-dimensional mesh is generated by joining together a plurality of the two-dimensional meshes in the direction of the rotation axis so that corresponding nodes in the two-dimensional meshes are connected by a straight line;

- e) dividing each of quadrangular elements constituting the boundary surface into two triangular elements arranged in a direction in which the boundary surface is twisted with respect to the stator-side mesh surface or the rotor-side mesh surface;
- f) connecting each of nodes constituting the stator-side mesh surface and the rotor-side mesh surface to a closest node among a plurality of nodes constituting the boundary surface by a straight line; and
- g) filling a space between each of surface elements constituting the stator-side mesh surface and rotor-side mesh surface and a combination of the two triangular elements connected to the surface element by straight lines, with four tetrahedrons, including two tetrahedrons comprising each of the two triangular elements as one face, and one quadrangular pyramid comprising the surface element as a base."

The auxiliary request 1 comprises further independent claims in different categories and analogous to the further independent claims of the main request.

IX. The appellant did not reply to the objections raised in the Board's communication and, in particular, did not make any submissions relating to D4 or to the prior art documents D6 and D7 introduced by the Board into the appeal proceedings.

In the statement of grounds of appeal, the appellant essentially put forward the following arguments:

- D1 and D2 failed to disclose some essential aspects of the present invention and, in particular, filling tetrahedrons and quadrangular pyramids into the cylindrical gap of the generated three-dimensional mesh, in consideration of the skew;
- the interpretation of the subject-matter of claim 1 on the basis of the original disclosure required that the method steps of claim 1 be read in their respective order;
- D2 explicitly taught to provide a 3-D stator-mesh and a 3-D rotor-mesh and to model the air gap between the stator and the rotor by a two-dimensional mesh surface as shown in Figure 2 of D2.

Furthermore the appellant referred to the arguments presented to the examining division in a letter dated 19 June 2007. They can be summarized as follows:

The subject-matter of the invention was based on a particular approach to modelling the air gap between the stator and the rotor of a rotating machine. As shown in Figure 1 of the application, the stator and the rotor were modelled by two-dimensional concentric meshes with an air gap ring between them. Instead of modelling the air gap by combining the 2-D rotor mesh and the 2-D stator mesh at an interface in the middle of the air gap, as taught in D1, a first initial three-dimensional mesh was generated by stacking a plurality of the two-dimensional meshes. This resulted in a three-dimensional rotor mesh and a three-dimensional stator mesh with a cylindrical air gap therebetween.

The cylindrical gap was thus composed of a stack of ring-shaped gaps and did not include the stator mesh or the rotor mesh. Next, a boundary surface was projected into the air gap and then the spaces between the gap and the surface in the stator mesh and the rotor mesh were filled with three-dimensional polyhedrons, resulting in a three-dimensional polyhedron mesh in the air gap as shown in Figure 1e.

A particular effect of the method of the invention and, in particular, of the fact that portions facing each other with the ring-shaped gap therebetween were divided into an equal number of parts was that portions of the stator-side and of the rotor-side of the three-dimensional mesh which came into contact with each other at the boundary surface were composed of elements having equal size in the rotation direction, and that it was possible to rotate a rotor-side of a three-dimensional mesh representing a rotating machine having skew by shifting the elements from the boundary surface. This resulted in reduced calculation time for the finite element method using the 3-D mesh of the invention compared to the prior art models.

## **Reasons for the Decision**

### *Admissibility*

1. The appeal is admissible.

### *Preliminary observations*

2. The present application addresses the problem of performing numerical analysis by the finite element analysis of a "rotating machine having skew that is a structure of the stator or the rotor twisted in the direction of the rotation axis" (see paragraph [0006], column 2, lines 30 to 33 of the application as published).
- 2.1 The Board is aware that an application concerned with finite element analysis and focusing in particular on a method for generating a three-dimensional mesh may give rise to questions relating to features which could be regarded as non-technical and as such would not contribute to an inventive step.

In the present case, this aspect of the application was not considered in the first instance and need not be addressed by the Board, as it is not relevant to the outcome of the appeal.

### *Decision of the examining division*

3. In the contested decision, the examining division considered that D1 constituted the closest prior art document and that the problem to be solved by the present invention could be regarded as extending the method disclosed in D1 to allow the creation of a

three-dimensional model of a rotating machine having a skewed rotor.

- 3.1 D2 disclosed a method that allowed the creation of a three-dimensional mesh for a rotating machine having a skewed rotor, whereby the three-dimensional mesh was generated by joining together a plurality of the two-dimensional meshes with the stator-side portion and the rotor-side portion relatively rotated on the rotation axis according to the twisted structure.
- 3.2 In combining the features disclosed in D1 and D2, the remaining features of claim 1 then on file would be realized automatically in the sense that the person skilled in the art would consider them as straightforward possibilities.
- 4. In the statement of grounds of appeal, the appellant stressed that the present invention was directed to a rotating machine having a skew and that, as specified in paragraph [0006] of the description, it was not possible to use a conventional three-dimensional mesh generating method because the shape of the rotating machine was not symmetric about a plane perpendicular to the rotation axis.
  - 4.1 D1 was only concerned with two-dimensional rotor and stator meshes. As to the assessment under point 8.2 of the contested decision according to which the skilled person was assumed to use those features of D2 needed to solve the technical problem, the appellant argued that it was based on hindsight as the remaining teaching of D2 was not considered. D2 explicitly taught to provide a 3-D stator mesh and a 3-D rotor mesh, and to model the air gap between the stator and the rotor



by a two-dimensional coupling mesh as shown in Figure 2 of D2.

In summary, neither D1 nor D2 nor any of the other documents taught to exclude the ring-shaped gap when stacking two-dimensional rotor and stator meshes.

5. As to the prior art D1 and D2 relied upon by the examining division, the Board agrees with the appellant that these documents do not cover certain aspects of the invention, such as generating a three-dimensional mesh for the stator and the rotor of a rotating machine with a skew by stacking two-dimensional rotor and stator meshes, and filling the ring-shaped gap between the rotor and the stator with polyhedra.

*Main Request*

6. Claim 1 according to the main request relates to a *"method for generating a three-dimensional mesh representing a rotating machine [...] by a combination of a plurality of polyhedrons"*, whereby the rotating machine includes the following features:

- a stator,
- a rotor rotating around a rotation axis, and
- a spatial area among the stator and the rotor, either or both of the stator and rotor having a skew configured with a twisted structure in a direction of the rotation axis of the rotor.

The method according to claim 1 comprises the following steps:

- a) generating a two-dimensional mesh for a plane of the rotating machine perpendicular to the rotation

axis, which includes polygons for the rotor and polygons for the stator;

- b) generating another two-dimensional mesh for another plane of the rotating machine perpendicular to the rotation axis, based on the twisted structure;
- c) generating an initial three-dimensional mesh for a solid of the rotating machine by stacking a plurality of the two-dimensional meshes, in accordance with the direction of the rotation axis, which includes polyhedrons for the rotor and polyhedrons for the stator;
- d) filling a space among the polyhedrons for the rotor and the stator of the generated initial three-dimensional mesh with tetrahedrons and a quadrangular pyramid, to generate the three-dimensional mesh.

6.1 As pointed out by the appellant in the statement of grounds of appeal, claim 1 according to the main request differs from claim 1 considered in the contested decision in that, *inter alia*, it specifies that the rotating machine has a skew and that a space left between the stator and rotor after generating the three-dimensional meshes for the rotor and the stator is filled with tetrahedrons and a quadrangular pyramid.

7. D4, which as indicated in the communication dated 26 November 2013 represents in the Board's view the closest prior art, is concerned with a method to generate and rotate 3-D finite element meshes for skewed rotor induction motors. As pointed out in Part II., prior to the generation of the 3-D mesh, the 2-D

multi-slice meshes are constructed according to the following steps:

- the basic 2-D mesh at the cross-section of the induction motor is firstly generated as the base-plane for the 2-D multi-slice meshes;
- the stator part and the rotor part of the 2-D mesh are generated separately;
- the stator and rotor mesh interface in the air-gap is divided equally, in the example of Figure 2, the air gap is divided into three layers, whereby the two upper layers belong to the stator and the one lower layer belongs to the rotor;
- the meshes of the other slices can be obtained by rotating the basic rotor mesh by an appropriate small angle.

As explained in Section III B. a triangular prism is to be extruded from a 2-D triangular element in the 2-D multi-slice mesh. The top of the prism comes from one of the slices of the 2-D multi-slice mesh, while the bottom of the same prism comes from the adjacent slice of the 2-D multi-slice mesh.

In other words, D4 discloses a method for generating a three-dimensional mesh representing a rotating machine by a combination of a plurality of polyhedrons, whereby the machine comprises a stator, a rotor rotating around a rotation axis, and a spatial area among the stator and the rotor, the rotor having a skew configuration with a twisted structure in a direction of the rotation axis of the rotor.

- 7.1 The method disclosed in D4 comprises therefore steps a) to c) recited in claim 1 of the appellant's main request.

As to step d) of claim 1, the method disclosed in D4 comprises:

- filling a space among the polyhedrons for the rotor and the stator of the generated initial three dimensional mesh with tetrahedrons to generate a three dimensional mesh.

7.2 The method according to the invention thus differs from the method shown in D4 only in that a space between the rotor and the stator is filled not only with tetrahedrons but also with a quadrangular pyramid.

7.3 The present application is silent about any possible advantage that may derive from using a combination of tetrahedrons and a quadrangular pyramid to fill "*a space among the polyhedrons for the rotor and the stator of the generated initial three-dimensional mesh*".

7.4 Starting from D4 a problem addressed by the present application could be seen in proving an alternative method for generating a three-dimensional mesh in the gap of a rotating machine with a skew.

8. D6 relates to an automatic mesh generation method for analyzing an air gap between a stator and a rotor of a rotary machine. As explained in paragraph [0009], firstly "*a stator spatial mesh 21 and a rotor spatial mesh 22 are prepared, while there is no mesh in the air gap 4. After the mesh data is input, in the computer, inside the air gap 4, a layer mesh 23 in contact with the stator spatial mesh 21, or a layer mesh 24 in contact with the rotor spatial mesh 22, or both of them are formed and a residual air gap 40 is automatically*

*divided into elements. Whenever the rotor space 3 rotates, only the residual air gap 40 is automatically divided into elements by the calculator".*

Figures 4a to 4d of D6 illustrate the process of the automatic mesh generation summarized in the flow chart of Figure 5. As pointed out in paragraph [0027], a mesh within the air gap 40 is formed *"by using tetrahedral elements and or pyramidal elements, vertices of which are points projected in the radial direction from certain points (for example, center points) on each element surface of layer meshes 23 and 24 prepared at step 1 of the first embodiment. The constituent elements of the top mesh 26 are tetrahedral elements when the surface elements of the layer meshes 23 and 24 form a triangle and pyramidal elements when the surface elements form a quadrilateral"* (emphasis added).

8.1 D7 gives in its introductory part some background information on mesh generation and on the desirability of employing quadrilateral meshes in some computer simulations (see for instance column 1, lines 9 to 15). In particular, according to D7 it is desirable that a quadrilateral mesh is automatically generated for a complicated curved shape (see D7, column 1, last line to column 2, line 2). On the other hand, fine mesh elements are preferably generated for important portions, in order to reduce computation time of applications (see D7, column 1, lines 52-54).

8.2 In the light of D6 and of the general background knowledge referred to in D7, it would be obvious to a person skilled in the art, wishing to generate a three-dimensional mesh according to the teaching of D4, to consider the possibility of filling a space in the air gap between the rotor and the stator not only with

tetrahedrons but also with a quadrangular pyramid. In doing so, the skilled person would arrive at a method falling within the terms of claim 1 of the main request.

- 8.3 Hence, the subject-matter of claim 1 according to the main request does not involve an inventive step within the meaning of Article 56 EPC.

Auxiliary Request 1

9. Claim 1 according to the auxiliary request 1 is based on a combination of steps a) to d) corresponding to claim 1 considered by the examining division, and of additional steps for generating a 3-D mesh from 2-D meshes and filling "a space" with tetrahedrons and one quadrangular pyramid.

- 9.1 In claim 1 of auxiliary request 1, the steps of generating the two-dimensional meshes and the initial three-dimensional mesh, and of filling the air gap delimited by the rotor and the stator are further detailed as follows:

- (a) portions of the two-dimensional mesh of the rotor and the stator facing each other with the ring-shaped gap therebetween are equally divided into mutually equal number of parts, and a stator-side portion and a rotor-side portion, excluding the ring-shaped gap, are represented by a combination of a plurality of polyhedrons on a plane perpendicular to the rotation axis (step "a)" in the filed claim);
- (b) generating an initial three-dimensional mesh by stacking a plurality of the two-dimensional meshes

with the stator-side portion and the rotor-side portion relatively rotated on the rotation axis according to the twisted structure, in the direction of the rotation axis according to a same rule in the stator-side portion and the rotor-side portion (step "b)" in the filed claim);

- (c) forming a boundary surface constructed by a mesh surface obtained by concentrically projecting, into a cylindrical gap composed of a stack of the ring-shaped gaps, any one of a stator-side mesh surface and a rotor-side mesh surface which face each other with the cylindrical gap therebetween (step "c)" in the filed claim);
- (d) filling spaces between the boundary surface and the stator-side mesh surface and rotor-side mesh surface with a plurality of polyhedrons, including polyhedrons comprising each of surface elements constituting the boundary surface, the stator-side mesh surface and the rotor-side mesh surface as one face, to generate the three-dimensional mesh (cf. step "d)" in the filed claim);
- (e) the two-dimensional mesh is comprised of a combination of a plurality of quadrangles;
- (f) the initial three-dimensional mesh is generated by joining together a plurality of the two-dimensional meshes in the direction of the rotation axis so that corresponding nodes in the two-dimensional meshes are connected by a straight line;
- (g) dividing each of quadrangular elements constituting the boundary surface into two

triangular elements arranged in a direction in which the boundary surface is twisted with respect to the stator-side mesh surface or the rotor-side mesh surface (step "e)" in the filed claim);

- (h) connecting each of nodes constituting the stator-side mesh surface and the rotor-side mesh surface to a closest node among a plurality of nodes constituting the boundary surface by a straight line (step "(f)" in the filed claim);
- (i) filling a space between each of surface elements constituting the stator-side mesh surface and rotor-side mesh surface and a combination of the two triangular elements connected to the surface element by straight lines, with four tetrahedrons, including two tetrahedrons comprising each of the two triangular elements as one face, and one quadrangular pyramid comprising the surface element as a base (step "g)" in the filed claim).

9.2 As to feature (f), its wording, which indeed corresponds to column 4, lines 26 to 31 of the published application, does not appear to reflect accurately how a 3-D mesh for the rotor and the stator is generated from corresponding 2-D meshes.

It is understood that the term "*initial three-dimensional mesh*" relates to the mesh generated in the space delimited by the rotor and the stator. Figure 5 is a schematic view for explaining the processes of generating such mesh. As pointed out in the published application (column 11, line 46 to column 12, line 9), "one layer of two-dimensional mesh as shown in FIG. 5(a) is stacked in the direction of the rotation axis, and the rotor side of the two-dimensional mesh is



rotated according to the structure of the skew. In the figure, M1 represents the first two-dimensional mesh, and M2 represents the stacked two-dimensional mesh. Next, corresponding nodes in the two-dimensional meshes are connected by a straight line between the stacked two-dimensional meshes to generate one layer of initial three-dimensional mesh. Further, as shown in FIG. 5(c), the next two-dimensional mesh M3 is stacked and the rotor side is rotated, and the same operation is repeated until the initial three-dimensional mesh representing the structure of the rotating machine is completed. FIG. 6 is a perspective view showing a part of the initial three-dimensional mesh. On the stator side, the initial three-dimensional mesh is generated by stacking two-dimensional meshes parallel to the rotation axis, while, on the rotor side, the initial three-dimensional mesh having a twisted structure according to the structure of the skew is generated" (underlining added).

In other words, the stacking is done in the direction of the rotation axis. However, only the stator 2-D meshes are joined together "in the direction of the rotation axis", whereas the straight lines joining the 2-D meshes on the rotator side are not parallel to the axis of rotation, as shown in Figure 6.

- 9.3 As specified in feature (c) above, the boundary surface in the gap is formed by projecting either the rotor-side mesh surface or the stator-side mesh surface on to a coaxial cylindrical surface within the gap. If the rotor-side mesh surface is used, the quadrangular elements of the boundary surface will show the same twist as the rotor-side mesh surface with respect to the stator-side mesh surface.

According to feature (g), each quadrangular element of the boundary surface is divided into two triangular elements *"arranged in a direction in which the boundary surface is twisted"*. Apart from implying that all triangles are arranged in the same direction, the impact of this feature on the generation of the mesh is not clear from the description of the invention.

9.4 Feature (h) specifies how each node of the boundary surface mesh is connected both to its closest node on the rotor-side mesh surface and to its closest node on the stator-side mesh surface.

9.5 Feature (i) is supposed to define how "a space" delimited by a rotor-side mesh surface element, a stator-side mesh surface element and two triangular elements of the boundary surface connected by straight lines to such rotor-side and stator-side elements is filled up with tetrahedrons and a quadrangular pyramid. It defines the following rules:

- it comprises four tetrahedrons;
- two of which have one of the two triangles as one face;
- one quadrangular pyramid has the surface element of the stator-side or of the rotor-side as a base.

As pointed out in column 14, lines 35 to 43 of the published application, the cylindrical gap is filled with polyhedrons periodically in the rotation direction, whereby the stator-side three-dimensional mesh and the rotor-side three-dimensional mesh match each other at the boundary surface SL.

10. Apart from the fact that the wording of claim 1 may give rise to clarity objections under Article 84 EPC,

some of the additional features referred to above are explicitly disclosed in D4 or D6, or necessarily implied by the prior art teaching.

- 10.1 As specified in Part III. *"Generation of 3-D Mesh"* of D4 (Section A. *"Extrusion of the Mesh"*), the *"3-D mesh is generated from its 2-D multi-slice mesh using the extrusion method. Tetrahedral elements are used in the mesh discretization. Here the extrusion of one triangular element in the axial direction will generate one triangular prism which will be further divided into 3 tetrahedrals"* (underlining added).

According to Part II. (Section II B. *"Generation of the Meshes at Other Slices"*), the *"geometrical difference between the basic slice and the other slices is that the other slices have rotated progressively by a small angle due to skewing in the rotor bars. The meshes at the other slices can be easily obtained by rotating the basic rotor mesh by an appropriate small angle"*.

This teaching of D4 corresponds essentially to features (b) and (f) referred to above. Furthermore, it is known from D6 that the initial two-dimensional meshes used to generate the 3-D meshes of the stator and the rotor may be comprised of a combination of a plurality of quadrangles as specified in feature (e) (see for instance Figure 2a of D6).

- 10.2 Feature (c) implies that the gap is divided into a rotor-side area and a stator-side by the boundary surface SL, as it is indeed the case in the second embodiment of D6 which specifies in paragraph [0027] that *"a cylindrical surface 30 is set"* in the space of the air gap 40 (see Figure 4a of D6).

Forming the boundary surface according to feature (c) by projecting the stator-side mesh surface or the rotor-side mesh surface into the cylindrical gap results in a boundary surface divided into quadrangular elements which are further divided into triangular elements (feature (g)). As shown below, the same result is achieved in D6.

10.3 As to features (d), (h) and (i), they relate to the generation of mesh elements in the air gap.

As shown in Figures 4a and 4b and specified in paragraph [0027] of D6, after setting the cylindrical surface in the air gap, a *"top mesh 26 is formed by using tetrahedral elements or pyramidal elements. [...]* The constituent elements of the top mesh 26 are tetrahedral elements when the surface elements of the layer meshes 23 and 24 form a triangle and pyramidal elements when the surface elements form a quadrilateral".

The cylindrical surface 30 is divided into the cylindrical surfaces 31 and 32, which respectively define the curved surface with which the *"stator spatial mesh 21"* and the *"rotor spatial mesh 22"* are directly and indirectly in contact (see Figure 5, step 3-1 and paragraph [0028], first sentence). The cylindrical surfaces 31 and 32 are then divided into two-dimensional triangular elements, as specified in step 3-2 of Figure 5. This results in the boundary surface being divided into triangular mesh elements similar to the ones shown in Figure 11 of the present application. In steps 3-3 and 3-4 of Figure 5, the air gap between the stator and the rotor is filled with tetrahedrons having one of the triangular mesh elements

of the surfaces 31 and 32 *"as a bottom"* (see Figure 6 and paragraph [0030] of D6).

Therefore, the method of filling the air gap with a 3-D mesh according to the second embodiment of D6 also involves tetrahedrons having triangular mesh elements of the boundary surfaces 31 and 32 as a base, and quadrangular pyramids when the surface elements of the the stator-side and the rotor-side are quadrilaterals.

For the skilled person a straightforward application of the teaching of D6 relating to the generation of an air gap mesh will result in filling *"a space"*, delimited by a quadrangular element of the stator-side mesh surface or the rotor-side mesh surface and by two triangular mesh elements of the boundary surface, with four tetrahedrons and one quadrangular pyramid, as specified in features (h) and (i).

11. As indicated in feature (a) of claim 1, the rotor-side portion and the stator-side portion of the two-dimensional meshes, which form the circumferential boundary of the gap, *"are equally divided into mutual equal number of parts"*.

This does not appear to be the case in the examples of D4 and D6.

- 11.1 However, the skilled person is aware that having an equal number of mesh elements in the circumferential direction can simplify the generation of the 3-D mesh, although it has the evident drawback that the dimension of an element of the 3-D mesh in the circumferential direction increases with the radial distance of this element from the axis of the motor. This implies that

the modelling of the outer cylindrical surfaces becomes less accurate.

For the person skilled in the art, this feature of the invention is an obvious trade-off between ease of calculation and accuracy of modelling.

12. In summary, D6 and the present invention share a common teaching, which consists in generating a 3-D mesh representing a rotating machine by filling the air gap between the rotor and the stator with a 3-D mesh comprising tetrahedrons and quadrangular pyramids.
- 12.1 As far as the generation of the 3-D mesh in the air gap is concerned, possible differences that may be seen between the method according to claim 1 of the auxiliary request 1 and the method known from D6 relate only to the particular sequence of steps (g), (h) and (i) performed to achieve the geometrical division of a space in the air gap into tetrahedrons and quadrangular pyramids, whereby both the present invention and D6 initially divide the air gap into two areas delimited by a common boundary surface and by the stator-side mesh surface and the rotor-side surface, respectively.
- 12.2 In the Board's opinion, it would be obvious to the skilled person, starting from the modelling of a skewed rotor induction motor disclosed in D4 and wishing to generate a 3-D mesh in the air gap according to the teaching of D6, to explore different possible ways of dividing the air gap space into tetrahedrons and quadrangular pyramids by joining the mesh nodes of the boundary surfaces with straight lines. In so doing, the skilled person can be expected to arrive at a method falling within the terms of claim 1 of the auxiliary request 1 without involving any inventive skills.

13. In summary, the Board finds that the subject-matter of claim 1 according to the auxiliary request 1 results from an obvious application of the teaching of D6 to a method for generating a 3-D finite element mesh, as known from D4, in combination with the skilled person's general knowledge in the field of automatic mesh generation (Article 56 EPC).
14. As both claim 1 of the main request and claim 1 of the auxiliary request 1 are not allowable, there is no need to consider the remaining independent claims.
15. Hence, the Board comes to the conclusion that none of the appellant's requests provides a basis for granting a patent. Consequently, the application has to be refused.

**Order**

**For these reasons it is decided that:**

The appeal is dismissed.

The Registrar:

The Chairman:



I. Aperribay

R. Moufang

Decision electronically authenticated