Development of technique for checking insulation distance for large-scale CAD data using voxel meshes

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Abstract

Conventionally, designers of electronic equipment structures visually inspect the insulation distance or check it by using CAD software functions. However, unintentionally failed detection and over-detection of objects being inspected can cause problems. Therefore, we are developing a technique for checking the insulation distance. The technique calculates the insulation distance by using voxels, which are in orthogonal meshes. The inputs of this technique involve checking conditions such as the clearance distance threshold and creepage distance threshold, setting part attributes such as of insulation and conduction, and calculating parameters such as voxel sizes. The output of this technique is the visualization of violating parts and paths detected by calculating the insulation distance and generating a distance map. We confirmed that our technique can measure the clearance and creepage distances, detect violation parts, and reduce over-detection of a model for inspection.

Keywords : Insulation distance, Computer aided design, Voxel mesh, Structural design, Electric equipment

1. Introduction

Electronic equipment needs to meet certain standards for insulation distance (IEC 60950-1, 2005)(JIS C 6950-1, 2012). The insulation distance is the distance between a high-potential part and a low-potential part. Two kinds of distance, clearance and creepage, are defined in the distance standard (Kobayashi et al., 2005). If the distance is less than a threshold, sparks may occur in the equipment. The insulation distances are different for each voltage and condition.

Conventionally, designers of electronic equipment structures visually inspect the insulation distance or check it by using CAD software functions. However, unintentionally failed detection and over-detection of objects being inspected can cause problems. For example, one function may over-detect pairs of a low-potential part and insulation part, pairs of a low-potential part and low-potential part, and pairs of a high-potential part and insulation part being obstructed by an insulation part.

The conventional methods for checking the insulation distance detect the shortest path and measure the distances between one high-potential part and one low-potential part. The shortest path and the distance of electrical creepage were researched by Kageura and Shimada et al. Conventional methods based on this research are intended for mainly twin parts. Therefore, measuring the insulation distance of a large number of part pairs will require many work hours.

The conventional methods for image processing calculate distance in a field. The methods are called “distance transforms” (Rosenfeld and Pfaltz, 1966). These methods were researched by Verwer, Grevera, Borgefors, Inui, Jones, Butt, Cuisenaire, Satherley, Marchand-Maillet et al. However, they may fail to detect violating parts for insulation distances because the calculated distance may be longer than the Euclidean distance.

Accordingly, to solve these problems, we are developing a technique for checking the insulation distance to calculate the distance by using voxels, which are in an orthogonal mesh. Our technique is for aiding in designing electronic equipment. The target is to conventionally reduce the number of work hours to half.

2. Technique for checking insulation distance

2.1 Problems with conventional methods

Insulation distances are shown in Fig. 1. If the distance is less than a threshold, sparks may occur in equipment. A summary of the conventional methods for checking insulation distances is shown in Table 1. Conventionally, designers of electronic equipment structures visually inspect the insulation distance or check it by using CAD software functions. However, unintentionally failed detection and overdetection of objects being inspected can cause problems. For example, one function may overdetect pairs of a low-potential part and insulation part, pairs of a low-potential part and low-potential part, and pairs of a high-potential part and insulation part being obstructed by an insulation part, as shown in Figs. 2(a) and (b). The measurement distance is L_m , and the insulation distance threshold is L_t . Insulation distance thresholds are determined by selecting the voltage and condition.

As mentioned, the conventional methods for checking the insulation distance detect the shortest paths and measure the distances between high-potential parts and low-potential parts, and conventional methods are intended for mainly twin parts. Measuring the insulation distance of a large number of part pairs is time-consuming, so our technique for checking the insulation distance calculates the distance by using voxels in an orthogonal mesh. The target is to conventionally reduce the number of work hours to half.

Fig. 1 Clearance and creepage distance

[The insulation distance is the distance between a high-potential part and low-potential part. Two kinds of distance, clearance and creepage, are defined in the distance standard. If the distance is less than a threshold, sparks may occur in equipment.]

Table 1 Summary of conventional methods for checking insulation distances

No.	Method	Selection of parts to verify	Detection accuracy	Creepage distance measurement	Work time	
					Operation time	Checking time
1	Visual inspection with 3D-CAD	User selection	Oversight of selected parts	Possible	Less than one hour	Unnecessary
2	Clearance verification function of 3D-CAD	Automatic (Full selection)	Overdetection	Impossible	Several minutes	Several hours
3	Method for finding shortest path between pair of points	User selection	Oversight of selected parts	Possible	Less than one hour	Unnecessary

Fig. 2 Examples of overdetection

[Clearance verification function of 3D-CAD may overdetect pairs of a low-potential part and insulation part, pairs of a low-potential part and low-potential part, and pairs of a high-potential part and insulation part being obstructed by an insulation part.]

Fig. 3 Flow chart for checking of insulation distances
[Conventionally, designers of electronic equipment structures visually inspect the insulation distance. However, unintentionally failed detection of objects being inspected can cause problems.]

In Fig. 3, the conventional distance transforms are Chamfer distance transforms (Richard Satherley and Mark W. Jones, 2001) in Eq. (1) to solve the overdetection problem. However, these transforms may fail to detect violating parts for insulation distances because the calculated distance may be longer than the Euclidean distance.

$$D(x, y, z) = \min \left((D(x + i, y + j, z + k) + d_{mat}(i, j, k)) \forall i, j, k \in d_{mat} \right), \quad \dots (1)$$

where $x, y, z, i, j, k \in \mathbb{Z}$

With our technique, we extract paths from low-potential parts to high-potential parts. The paths are extracted on the basis of a map by using Chamfer distance transforms. Furthermore, the distances are re-calculated by subtracting an assumed maximum error. In Eqs. (2) and (3), the error is φ , the distance of the path is L_p , the Euclidean distance is L_e , and the calculated distance is L_c . Therefore, the calculated distance is shorter than the Euclidean distance.

$$\varphi = L_p - L_e \quad \dots (2)$$

$$L_c = L_p - \max(\varphi) \quad \dots (3)$$

2.2 Overview of technique

The inputs of our technique involve checking conditions such as the clearance distance threshold and creepage distance threshold, setting part attributes such as of insulation and conduction, and calculating parameters such as voxel sizes. An overview of this is shown in Fig. 4. Even complicated CAD models can be simplified to the voxels of an orthogonal mesh (Watanabe and Nakahashi, 2010). The calculation time will be short if simplified shapes are used. The output of this technique is the visualization of violating parts and paths detected by calculating the insulation distance and generating a distance map. The user's job is to mainly input parameters, such as thresholds, and to pick parts. The

details on picking parts are given below.

The amount of work required to set part attributes is reduced by using a batch selection process for connecting parts, as shown in Fig. 5. First, users classify parts as conduction or insulation according to the material property in CAD. Next, they pick high-potential parts among conductive parts, and the associated parts are selected. Automatically, conductive parts connected to previously selected parts are searched for and selected as high-potential parts. This process iterates until no new parts are selected. By picking just a few parts, users can set part attributes easily.

The violating parts and paths are highlighted as shown in Fig. 6.

Fig. 4 Insulation check using voxel mesh

[Even complicated CAD models can be simplified to the voxels of an orthogonal mesh. The calculation time will be short if simplified shapes are used. The output of this technique is the visualization of violating parts and paths detected by calculating the insulation distance and generating a distance map.]

Fig. 5 Connected high-potential parts

[The amount of work required to set part attributes is reduced by using a batch selection process for connecting parts. First, users classify parts as conduction or insulation according to the material property in CAD. Next, they pick high-potential parts among conductive parts, and the associated parts are selected. Automatically, conductive parts connected to previously selected parts are searched for and selected as high-potential parts. This process iterates until no new parts are selected. By picking just a few parts, users can set part attributes easily.]

Fig. 6 Visualization of result
[The violating parts and paths are highlighted.]

2.3 Technique for calculating to prevent failed detection

Conventionally, distance transforms (DTs) (Rosenfeld and Pfaltz, 1966), known as distance field calculations, have been researched to measure the distance between cells of voxels in the image processing field. The Chamfer distance transform (CDTs) of an improved DT method could extract the shortest path approximately.

The clearance distance of our technique is calculated by using a quasi-Euclidean $5 \times 5 \times 5$ Chamfer distance matrix (Richard Satherley and Mark W. Jones, 2001). While the error of the distance is positive, the distance is longer than the Euclidean distance, as shown in Eq. (4). The error is φ_{dt} , and distance of the path extracted by using CDTs is L_{pdt} . The Euclidean distance on the voxel mesh is L_{ev} . If the insulation distance is shorter than the threshold regulated by the electric standard, the risk of failed detection increases.

$$\varphi_{dt} = L_{pdt} - L_{ev} \quad \cdot \cdot \cdot (4)$$

Therefore, we calculate the distances of clearance and creepage on the basis of extracted paths, as shown in Fig. 7. In this case, the Chamfer distance is longer than the Euclidean one. Accordingly, the conventional method is inadequate for calculating the insulation distance. In contrast, distances calculated by our technique are shorter than the Euclidean distance. In the case of the clearance distance, the paths can cross insulation cells until the cell size is less than half. Furthermore, our technique subtracts the maximum φ_{di} from the distance. The maximum φ_{di} is shown in Eq. (5). The cell size is L_{vs} , the number of the corners of a path is N_c , and the coefficient is C . The C of the clearance distance is the square root of 3. The main error of the technique is the difference between the CAD shape and voxel mesh.

Fig. 7 Calculated insulation distance
[The distances of clearance and creepage are calculated on the basis of extracted paths.]

$$\max(\varphi_{dt}) = L_{ps}(1 + CN_c) \quad \cdot \cdot \cdot (5)$$

The high-potential parts and low-potential parts of the voxel mesh of our technique expand in shape, as shown in Figs. 8 (a) and (b), and the shape of the insulation parts of the mesh contract, as shown in Fig. 8 (c). Therefore, the insulation distances on the voxel mesh are shorter than the CAD shape, as shown in Eq. (6). The Euclidean distance on the CAD shape is L_{ecad} .

Fig. 8 Voxel mesh for insulation check
[The high-potential parts and low-potential parts of the mesh of our technique expand in shape.]

$$L_{ecad} \leq L_{ev} \quad \cdot \cdot \cdot (6)$$

The distance map for the clearance distance is a quasi-Euclidean $5 \times 5 \times 5$ Chamfer distance matrix in our technique, as shown in Fig. 9.

Fig. 9 Distance map for clearance distance
[The map for this distance is a quasi-Euclidean $5 \times 5 \times 5$ Chamfer distance matrix in our technique.]

Examples of distance values are shown in Fig. 10. Case 1 shows voxels from the side. Case 2 shows voxels diagonally in two dimensions. Case 3 shows voxels diagonally in three dimensions.

Fig. 10 Distance values for clearance distance
 [Case 1 shows voxels from the side. Case 2 shows voxels diagonally in two dimensions. Case 3 shows voxels diagonally in three dimensions.]

The distance map for the creepage distance is a quasi-Euclidean $5 \times 5 \times 5$ Chamfer distance matrix in our technique, shown in Fig. 11.

Fig. 11 Distance map for creepage distance
 [The distance map for the creepage distance is a quasi-Euclidean $5 \times 5 \times 5$ Chamfer distance matrix in our technique.]

Examples of distance values are shown in Fig. 12. Case 1 shows voxels from the side. Cases 2 and 3 show voxels diagonally in two dimensions. Case 4 shows voxels diagonally in three dimensions.

Fig. 12 Distance value for creepage distance

[Case 1 shows voxels from the side. Cases 2 and 3 show voxels diagonally in two dimensions. Case 4 shows voxels diagonally in three dimensions.]

The start points of the path for extracting the clearance distance begin in the low-potential parts, as shown in Fig. 13 (a). The end points are in the high-potential parts. The path is a line that connects a cell whose value is added to the next cell value and whose distance to next cell is minimal, as shown in Figs. 13(b), (c), (d).

Fig. 13 Paths between high-potential and low-potential parts for clearance distance

[The start points of the path for extracting the clearance distance begin in the low-potential parts.]

The start points of the path for extracting the creepage distance begin in the low-potential parts, and the end points are in the high-potential parts. The path is a line that connects a cell whose value is added to the face of the next cell value and whose distance to the face of the next cell is minimal, as shown in Fig.14. For the creepage distance, the C of Eq. (5) is the square root of 2.

Fig. 14 Path between high-potential and low-potential parts for creepage distance

[The start points of the path for extracting the creepage distance begin in the low-potential parts, and the end points are in the high-potential parts. The path is a line that connects a cell whose value is added to the face of the next cell value and whose distance to the face of the next cell is minimal.]

2.4 Verification of Technique

The technique was verified, and it was found that all violating parts were detected by using test model 1, overdetections were fewer than 3D-CAD clearance verification with test model 2, work time was less than 3D-CAD clearance verification, and a large-scale 3D-CAD model can be checked by using test model 3. The characteristics of the three test models are shown in Table 2.

Table 2 Characteristics of test model

Model name	Human check	Shape	Number of conductive parts
Test model 1	Practicable	Complex	20
Test model 2	Hard	Simple	198
Test model 3	Very hard	Simple	10,029

3. Results

3.1 Test model 1

To confirm that our technique can detect all violating parts, we checked the insulation distance of a test model, model 1, using the technique. The model was made up of four modules that had the same shape. The model is shown in Fig. 15. The span of the model was 102 mm. Each of the modules had one high-potential part, four low-potential parts, and a few insulation parts. The clearance threshold of the model was 5 mm, and the creepage distance threshold was 9 mm, as shown in Table 3. The cell size of the calculating parameters was 0.015 – 0.2 mm. The number of threads in parallel computing was four, equaling the number of modules. While the cell size was 0.015 mm, the number of cells was 399,653,280.

We confirmed that our technique can measure clearance and creepage distances and detect the violating parts of a model for inspection, as shown in Fig. 16.

The technique detected two low-potential clearance violating parts and four low-potential creepage distance violating parts. All of the detected parts were violating parts in the model. The results are shown in Fig. 17. The error was the absolute value obtained by subtracting the insulation distance calculated by using our technique from the actual distance determined by using CAD software functions. While the cell size was 0.015 mm, the clearance maximum error was 0.7% (0.03 mm), and the creepage maximum error was 1.6% (0.11 mm). The errors were sufficiently small considering that

the span of the module was large. However, overdetection occurred in the error range. For example, if the cell size was 0.1 mm and 0.2 mm, overdetection occurred. However, the bigger the cell size was, the shorter the calculation time was.

Fig. 15 Test model 1 for missed detection

[To confirm that our technique can detect all violating parts, we checked the insulation distance of a test model, model 1, by using the technique. The model was made up of four modules that had the same shape.]

Table 3 Parameters of test model

Clearance threshold [mm]	Creepage distance threshold [mm]	Cell size [mm]	Number of threads in parallel computing
5	9	0.015 – 0.2	Max of 4

Fig. 16 Extracted paths of low-potential parts

[Our technique can measure clearance and creepage distances and detect violating parts of a model for inspection.]

Fig. 17 Result of insulation distance measurements
 [Overdetection occurred in the error range. For example, if the cell size was 0.1 mm and 0.2 mm, an overdetection occurred.]

3.2 Test model 2

To determine the number of failed detections and overdetections, we used our technique to test model 2 and compared it with the conventional method (clearance verification). The model consisted of 99 high-potential parts, 99 low-potential parts, and 46 insulation parts, as shown in Fig. 18 and Table 4. The clearance threshold of the model was 5 mm, and the creepage distance threshold was 10 mm. The cell size of the calculating parameters was 0.5 mm. The number of cells was 12,571,200.

Fig. 18 Test model 2
 [To confirm the number of failed detections and overdetections, we used our technique to test model 2 and compared it with the conventional method (clearance verification). The model consisted of 99 high-potential parts, 99 low-potential parts, and 46 insulation parts.]

Table 4 Number of parts

Category	Number of parts
High-potential parts	99
Low-potential parts	99
Insulation parts	46
Total	244

The work times of the model were 2.2 min with our technique and 5.2 min with the conventional method, as shown in Fig.19.

Fig. 19 Work time

[The work times of the model were 2.2 min with our technique and 5.2 min with the conventional method.]

The numbers of violating parts was 186 with our technique compared with 476 with the conventional method, as shown in Fig. 20. The numbers of overdetected parts were 298 with our technique compared with 8 with the conventional method. The numbers of missed detections were zero for both.

Fig. 20 Number of violations

[The numbers of violating parts was 186 with our technique compared with 476 with the conventional method. The numbers of overdetected parts were 298 with our technique compared with 8 with the conventional method. The numbers of missed detections were zero for both.]

3.3 Test model 3

To confirm the time taken to check the insulation distance of a large-scale model, we used our technique to test model 3 and compared it with the conventional method, as shown in Fig. 21. The model size was 500 mm. The clearance threshold of the model was 1 mm, and the creepage distance threshold was 2 mm. The cell size of the calculating parameters was 0.5 mm. The number of cells was 10,978,000.

The operation times were 5 min with our technique and 120 min with the conventional method, as shown in Fig. 22. The calculation times were 25 min with our technique and 20 min with the conventional method. The times taken to check the insulation distance were 30 min with our technique and 140 min with the conventional method. The number of work hours taken to check the insulation distance was reduced by 78% in the models.

Fig. 21 Large-scale model

[To confirm the time taken to check the insulation distance of a large-scale model, we used our technique to test model 3 and compared it with the conventional method.]

Fig. 22 Time for checking insulation distances

[The operation times were 5 min with our technique and 120 min with the conventional method. The calculation times were 25 min with our technique and 20 min with the conventional method. The times taken to check the insulation distance were 30 min with our technique and 140 min with the conventional method.]

4. Discussion

The errors were big so that the cell size was big, as Fig. 17 indicates. In low-potential part no. 1 of model 1, if the cell size was 0.1 mm, the maximum error was 4.3% (0.31 mm), and there was no overdetection. If the cell size was 0.2 mm, the error was 82.2% (5.84 mm), and overdetection occurred. Because insulation parts disappear due to the simplification caused by using voxels, the error for this cell size was too big. Accordingly, it is necessary for the cell size to be less than the minimum thickness of the insulation parts.

In model 2, which included 178 violating parts, the numbers of overdetection parts when using both the technique and conventional method were 8 and 298, respectively, when using CAD software functions. In model 3, the number of work hours using both was 5 min and 120 min when using CAD software functions. Then, the calculation times when using both were 25 min and 20 min when using CAD software functions. We confirmed that our technique reduces the number of overdetections and the number of work hours of a model for inspection. Accordingly, our technique will reduce the number of work hours to less than half.

5. Conclusion

Conventionally, designers of electronic equipment structures visually inspect the insulation distance or check it by using CAD software functions. However, unintentionally failed detection and overdetection of inspection objects can cause problems. Therefore, we are developing a technique for checking the insulation distance to calculate it by using voxels, which are in orthogonal meshes. The target is to conventionally reduce the number of work hours to half.

We applied our technique to test models and got the following conclusions.

1. We confirmed that the technique could measure clearance and creepage distances and detect all violating parts of models for inspection.
2. We confirmed that the number of overdetected parts was eight (4%) with our technique compared with 298 (167%) with the conventional method when using CAD software functions for a model including 178 (100%) violating parts.
3. We confirmed that the number of work hours taken to check the insulation distance was reduced by 78% in the models. Accordingly, our technique will reduce the number of work hours to less than half.

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