Structural Design and Analysis for 3D Ultrasonic Anemometer

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Abstract

A 3D ultrasonic anemometer measures the direction and velocity of wind in a 3D space. The 2D ultrasonic anemometers developed by different manufacturers do not differ significantly in terms of their form or structure. The 3D ultrasonic anemometers, on the other hand, have more diverse forms than their 2D counterparts depending on the measurement algorithms and methods. Designing and reviewing the structure at the initial stage and defining its performance objectives are time-consuming processes. The process can be made cost-effective and time-saving if the validity is tested by model design and structural interpretation, and the structure is designed to withstand high wind velocities. This study presents the results of a 3D ultrasonic anemometer on real sample data by using a 3D modeling program, CATIA, for ultrasonic anemometer modeling.

Keywords: 3D ultrasonic anemometer, 2D ultrasonic anemometer, wind sensor, wind tunnel, structural interpretation

1. INTRODUCTION

Ultrasonic-type wind sensors do not suffer from the limitations of mechanical anemometers (such as the cup anemometer) that require change and recalibration for different operations \cite{1}. The ultrasonic sensors can measure high velocity and have a good precision, and are therefore expected to be utilized in different fields. These sensors also allow measurement of the atmospheric temperature from velocity without the need of a temperature sensor \cite{2}. The ultrasonic anemometer has advanced with the development of the 3D anemometer, now commercially available, that includes ascending air and downdraft. The 2D ultrasonic anemometers developed by different manufacturers usually make measurements in a similar way irrespective of the plane, form or structure.

Signal analysis is performed either on the directly received ultrasonic signal or on the signal reflected from the ceiling.

Depending on the anemometer it uses two sensors to measure the wind velocity for directly received ultrasonic signals, or three to four sensors to measure wind velocity and wind direction. While the frequencies and algorithms of receiving may vary with manufacturers, sensor arrangements (facing each other and ceiling) have a set structure similar in all 2D configurations.

On the contrary, the 3D ultrasonic anemometer has various forms and structures, and involves optimization based on specialty, specification, and measurement algorithms. Specifically, an anemometer that has been designed to measure a velocity of more than 70 m/s needs significant time for its initial design process. However, if the design can withstand high velocities, and the validity is tested by through modeling and structural interpretation, this process can be made time- and cost-effective.

This study performs a fluid and structural-coupled field analysis by modeling using the 3D CATIA software \cite{3} for designing the 3D anemometer structure. In addition, we made measurements using a wind tunnel with a validated 3D ultrasonic anemometer. The 3D ultrasonic anemometer used in this study is designed such that each pair of anemometers face one another.

2. EXPERIMENTAL

2.1 3D Modeling of the ultrasonic anemometer using CATIA

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To perform 3D floating analysis and structure interpretation, we perform modeling of the ultrasonic anemometer in CATIA 3D modeling program. Fig. 1(a) shows the 3D shape of the ultrasonic anemometer used to perform floating interpretation, modeling. Fig. 1(b) shows the grid system of outer wall of the anemometer as created in ANSYS ICEM_CFD 15.0 [4]. The lattice for the 3D floating analysis [5] and structure interpretation is composed of 6,000,000 nodes and 3,500,000 elements. The flow field is mainly composed of tetrahedrons, and the prism lattice is used to improve the accuracy for the wall.

To perform floating analysis, we set 70 m/s as the maximum velocity of outflow to pass through the 3D anemometer so as to test the structural safety of anemometer for maximum wind speed.

2.2 Structural analysis using ANSYS

In this paper, we perform coupled analysis of the material construction to test the structural safety of the anemometer. We impose fluid structural interaction such that the flow field calculated by using ANSYS-CFX 15.0 [6] includes anemometer pressure.

The ANSYS Mechanical (workbench) is used for grid system programming where the pressure data is calculated using ANSYS-CFX through interpolation. The values are re-set into the grid system and calculated after changing the data to pressure weights for structure interpretation. Fig. 2 shows the analysis map for the fluid-structural interaction (FSI).

Changing 3D model to Floating model and calculated and analysis, after changed 3D Floating grid model. Fig. 3 shows the grid system used for fluid analysis.

3. RESULTS AND DISCUSSIONS

This section presents the results and analyses for the 3D ultrasonic anemometer.

3.1 Observations and analyses of various characteristics

Various characteristics of the 3D ultrasonic anemometer, such as surface pressure, wall shear-force, stress distribution and surface deformation, are discussed as observed from the results.

3.1.1 Streamlining around Ultrasonic anemometer

Fig. 4 shows a streamlining around the stage-1 sensor of the ultrasonic anemometer for an inlet velocity of 70 m/s. It may be observed that this sensor structure is not affected by floating, and the main floating, along the vertically-set left and right sensors, makes a strong slip stream. The back of the cylindrical structure supporting this sensor produces recirculation and delamination, and displays a complicated floating.

The longitudinal-end section of the sensor shows the maximum velocity distribution; the upper end of the sensor and the pipe of connected to the lower part also show also a maximum velocity due to their strong structural resistance.

The lower sensors display a maximum velocity in the
longitudinal-end sections similar to streamline. These observations suggest that the ultrasonic anemometer sensor would suffer a serious shaking due to the wind strength. This limitation occurs if we simply use the sensor structure of the 2D ultrasonic anemometer in a 3D configuration because the horizontally-set sensor structure is not suitable to be used as a 3D ultrasonic sensor structure. As a result of this experiment, we increase the pipe thickness from 1.0 T to 1.5 T to ensure the safety of the prototype.

3.1.2 Surface pressure

Fig. 5 shows the pressure distribution on a surface of the ultrasonic anemometer for an inlet velocity 70 m/s. We calculate the deformation and stress of the 3D anemometer by applying a loading condition for structure interpretation. As shown in Fig. 7, the part of the structure facing the flow receives a higher pressure; a pressure of approximately −10,000 Pa shows up at the end of sensor. As the maximum and minimum pressures are 20,000 Pa and −10,000 Pa, respectively, the net difference is approximately 30,000 Pa.

3.1.3 Wall Shear force

Fig. 6 shows the wall shear distribution on a surface of the 3D ultrasonic anemometer. The surface shear force has maximum value of 200 Pa, and the net pressure is 30000 Pa as shown in the pressure distribution result of Fig. 9. As the difference is less than 1%, we choose to ignore its effect on the structure.

3.1.4 Equivalent stress distribution

To evaluate the structural safety, which is affected by the wind velocity, we analyze the distribution on a surface of the ultrasonic anemometer obtained from float analysis by applying load boundary condition.

As mentioned earlier, the variable that affects structure deformation by floating is predominated by the surface pressure, and the shear force can be ignored. Thus, in this paper, we used only pressure condition for structure analyzing for boundary condition. Fig. 7 shows the result of the fluid structure coupled analysis applied with boundary conditions of the resultant shear force. An equivalent stress distribution is observed for the forming structure. The maximum stress value is approximately 10 MPa from the connection of stage-1 and -2 sensors.
3.1.5 Surface deformations

Fig. 8 shows the total deformation distribution on a surface of the ultrasonic anemometer. It is apparent that the connection between the sensor stages 1 and 2, and the end stage-2 sensor shows the maximum deformation. The maximum deformation is approximately 0.07 mm, which is a considerably small value, and the structural safety can thus be considered satisfactory.

We have tested the structural feature of the 3D ultrasonic anemometer using CATIA flow analysis. In the analysis of flow around the anemometer, we found that the highest velocity distribution occurs at the end of the sensor, and that the wind could create a mechanical wobble in this sensor. This problem occurs when the 2D ultrasonic anemometer is used for the 3D sensor. As the sensor length is fixed, this problem cannot be addressed unless the sensor is changed. We therefore increase the pipe thickness to 1.5 T in order to prevent wobbling even by strong winds. In view of the limitations of the ultrasonic sensor designs, we propose to develop a prototype of the existing design.

3.2 Development of the anemometer and measurement of wind tunnel

The description and the performance of the developed prototype anemometer are discussed as follows.

3.2.1 Prototype ultrasonic anemometer

Fig. 9(a) shows drawings of the various views of the ultrasonic anemometer, along with Fig. 9(b) shows the picture of the developed anemometer prototype. It is composed of SUS304 for maintenance of hardness and protection again corrosion. 1.5 T pipes are used in all instances.

3.2.2 Environment

Fig. 10 shows the test bed of the ultrasonic anemometer. It comprises a wind tunnel to measure wind, and an ultrasonic anemometer setup.

3.2.3 Performance of the developed ultrasonic anemometer

Fig. 11 displays the results for the wind tunnel of the 3D
ultrasonic anemometer. The measured values depend on the grade or the direction and speed of the wind [7, 8]. Results are found to exhibit comparatively linear characteristics for the wind direction and velocity measurements. As the calibration of wind direction and velocity was not carried out, the results do not match with the guidelines. However, if the calibration is performed without hunting section, it may be possible to reach the accuracy of a 2D ultrasonic anemometer.

4. CONCLUSIONS

The 3D ultrasonic anemometer sends and receives ultrasonic signals not in a two-dimensional plane, but in a three-dimensional atmosphere through each of the three partner sensors. While its appearance is similar to a normal ultrasonic anemometer, its performance depends on the kind of support it utilizes. If the support connecting the upper sensor upper with the bottom sensor is too thin, it may bend; if it is too big and thick, it would create turbulence in during measurements. The performance may vary depending on the length, strength and the material of the support.

It is important to properly model the process so that the target performance is achieved, and certain problems do not lead to the requirement of a full re-designing. Our 3D ultrasonic anemometer is found to display stable performance.

Among the several ways to achieve structural stability, we have used 3D modeling and flow analysis by CATIA. We also tested the stability of the performance through a wind tunnel setup in the 3D ultrasonic anemometer. This study helps us realize the importance of structural stability in 3D ultrasonic anemometers, and we aim to continue working towards further refinement of the structural design.

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