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Research paper

Transducer Development and Modeling for Mass Air Flow Sensor

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Abstract

The article describes the development of the computer model and the modeling of mass air flow sensor using SolidWorks and ANSYS software. Using SolidWorks, a three-dimensional model of a mass air flow sensor was created, then this model was transferred to the ANSYS software complex, where transducer functioning process was modeled by finite element method. Several variants of sensor transducer elastic element geometry were considered and an optimal design was chosen.

Keywords: *transducer, mass air flow sensor, strain gauge, computer model, finite element method, elastic element, relative deformation*.

1. Introduction

According to the number of failures, the mass air flow sensor occupies the third place among the elements of the internal combustion engine [1-4], which emphasizes the urgency of new reliable sensor design development.

It is proposed to use an elastically bendable blade in the developed design of the mass air flow sensor as a sensitive element (the converter of physical quantities). The integral bending of this blade is proportional to the mass flow of air. At that, in order to measure a blade integral bend strain gauges will be used located at certain points on its surface. The shape and the design of a blade is made taking into account the obtaining of an optimal elastic flexibility within the given integral deflection.

The strain gages are connected according to the Winston bridge scheme (4 strain gages, 2 on the front side of a blade and 2 on the back side of a blade), which leads to the measured voltage and measuring circuit sensitivity increase. The temperature change of strain gauge resistance is compensated, since all strain gauges are in the same conditions.

The sensor functions in the following way [5]. When the air speed changes, the aerodynamic effect of the flow on the measuring blade also changes. At that the integral value of the blade deformation also changes, as well as deformation of the strain gauges applied to the blade: the electrical resistance increases with the front strain gauges, and decreases with the rear ones and, consequently, the balancing of the measuring bridge changes. The signals are fed from the measuring bridge into the microprocessor module, where the air mass flow rate is calculated according to a certain algorithm [6].

2. Sensor Model

The modeling of mass air flow sensor is necessary in order to relate the processes of aerodynamics, elastic deformation and sensor design. The computer model of the sensor is implemented using the software complexes SolidWorks and ANSYS. Figure 1 shows the different versions of the converter elastic element, created in SolidWorks. In addition to the elastic elements, Figure 1 shows the part of the inlet pipe that is necessary to set the fixing conditions. The considered flexible elements have the thickness of 0.2 mm.

In order to simulate the effect of air flow on the elastic element, a three-dimensional model of the air region was also created in the form of a cylinder with an external diameter of 63 mm and the element length of 150 mm. The models of the elastic element and the air region were combined into an assembly using the SolidWorks program, the distances from the ends of the cylindrical surfaces of the air region to the middle plane of an elastic element were 75 mm. Then this assembly was transferred to the ANSYS software package for further modeling.

The transducer model was removed from the module meshing, since it is not required in the gas dynamic calculation. Then, a finite element grid of the air area was created in the same module, through which the calculation of the air flow effect on the converter is performed. The grid consists of hexahedral elements with 2.1 million elements and 7.7 million of network nodes.

Then the calculation data were set in the CFX-Pre module (A4 cell in the project tree on Figure 2). The domain was created with the name Air (Figure 4) for the airspace geometry. Fluid Domain type was selected in the Basic Settings tab in Domain Type cell, which corresponds to the fluid or gas description in CFX solver. The air of 25 °C was chosen as the material, but it is possible to choose any other material, and also to specify your own material with a set of all necessary properties. The models of heat exchange and flow turbulence were set in the Fluid Models tab. This calculation has no heat transfer, and the shear stress transport model was chosen as the model of turbulence.

The second Fluid Flow (CFX) module on Figure 2 simulates a flow with the same geometry, the finite element grid and boundary conditions, but with a different mass flow rate.

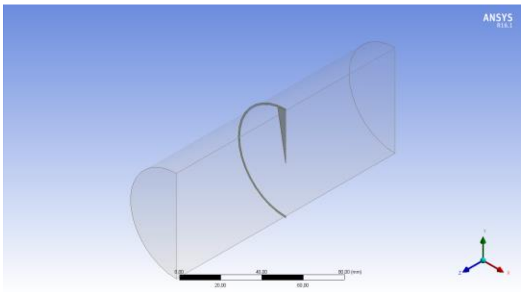

Fig 1: Assembly geometry adjusted in Design Modeler

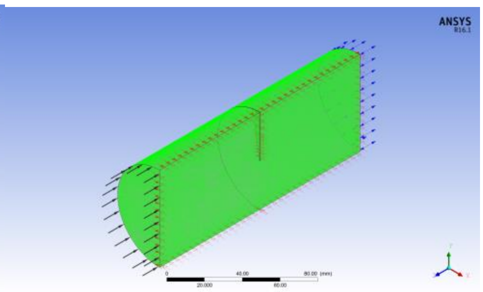

Fig 2: The setting of properties for Air domain

After the completion of the gas dynamic calculation in the Engineering Data module (cell C2 in the project tree on Figure 2) the materials are set with the necessary characteristics for strength analysis. In our case, the material is 36HXTU with the following parameters: Young's modulus - 1.9 10^5 MPa; the shear modulus makes 77 500 MPa. Then the geometry of the calculation area, constructed earlier, is transferred to the Static Structural module, for which the project cells A2 and C3 are connected. After that, the ANSYS Mechanical module is started The total number of grid elements is 56,000, and the total number of grid nodes is 300,000 (Figure 3).

Then the conditions to secure the elastic element Fixed Support are set, which prohibit the movement of selected surfaces in all directions. The values of pressures on the converter surface are calculated in the Fluid Flow (CFX) module and are transferred to the Setup unit (cell C5 of the project), for this the cell A5 and C5 are connected in the project tree. The pressures transmitted to ANSYS are shown on Figure 4.

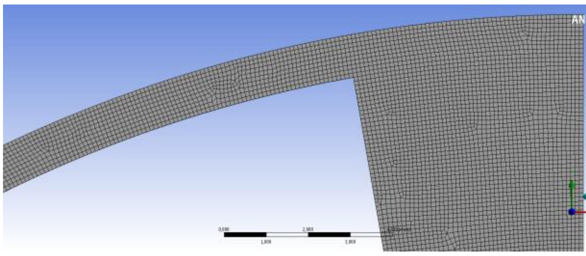

Fig 3: Transducer final element mesh

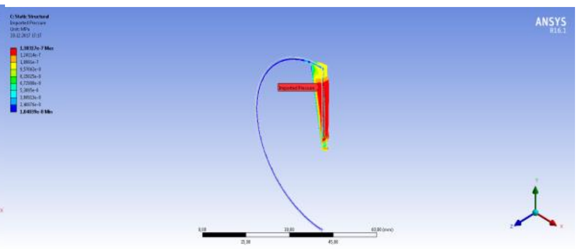

Fig 4: Pressures, described in ANSYS Mechanical from Fluid Flow (CFX)

The second module of the Static Structural project works in a similar way. The only difference is that it is calculated at the pressures corresponding to another air flow (600 kg/h).

3. Results of Modeling

Since the converter measures the mass flow of air using strain gauges, then it is necessary to install them in places with the greatest radial relative deformations for the greatest sensitivity. It is also necessary to take into account that the relative deformations at the maximum air flow should not reach the yield point of the elastic element material since this will lead to the appearance of residual deformations and incorrect measurements of the air mass flow rate. Figure 5 shows the radial relative deformations of the elastic elements in the form of a triangle and a V-shaped one with the angle of 90°.

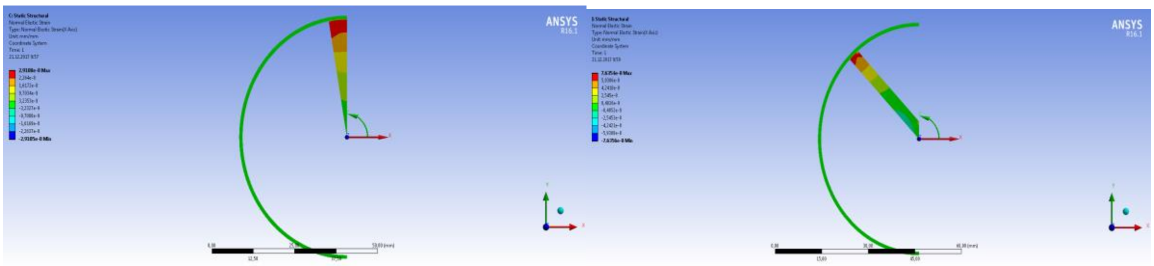

Fig 5: Relative deformations of elastic elements in the radial direction

Fig 7 shows that the greatest relative deformations are at the root section of an elastic element. Thus, the best location of the strain gauges is the base of an elastic element.

Table 1 summarizes the results of various types of elastic element modeling with the air flow values equal to 5, 100, 300 and 600 kg/h, respectively.

Table 1: Elastic element simulation results with the thickness of 0.2 mm

Elastic element structure	Relative deformations at the expense of air			
	5 kg/hour	100 kg/hour	300 kg/hour	600 kg/hour
Triangular	$2{,}014\cdot10^{-8}$	$6{,}765\cdot10^{-6}$	$6{,}013\cdot10^{-5}$	$2{,}379\cdot10^{-4}$
V-shaped 60°	$5{,}192\cdot10^{-8}$	$1{,}852\cdot10^{-5}$	$1{,}649\cdot10^{-4}$	$6{,}567\cdot10^{-4}$
V- shaped 90°	$5{,}204\cdot10^{-8}$	$1{,}858\cdot10^{-5}$	$1{,}656\cdot10^{-4}$	$6{,}595\cdot10^{-4}$

Table 2: Results of elastic element simulation with the thickness of 0.15 mm

Elastic element structure	Relative deformations at air expense			
	5 kg/hour	100 kg/hour	300 kg/hour	600 kg/hour
Triangular	$3{,}65\cdot10^{-8}$	$1{,}228\cdot10^{-5}$	$1{,}084\cdot10^{-4}$	$4{,}307\cdot10^{-4}$
V- shaped 60°	$9{,}428\cdot10^{-8}$	$3{,}361\cdot10^{-5}$	$2{,}994\cdot10^{-4}$	$1{,}192\cdot10^{-3}$
V- shaped. 90°	$9{,}459\cdot10^{-8}$	$3{,}366\cdot10^{-5}$	$2{,}996\cdot10^{-4}$	$1{,}192\cdot10^{-3}$

It can be seen from Tables 1 and 2 that at any design of the elastic element, the relative deformations do not reach the yield strength of an elastic element material (equal to the steel 36NXTiO 2.10-3), while the relative deformations at the thickness of the elastic elements 0.15 mm are larger than at the thickness 0.2 mm in 1.8 times. Thus, in order to increase transducer sensitivity, it is advisable to use elastic elements with the thickness of 0.15 mm.

Further calculations of elastic elements were carried out at the thickness of 0.15 mm with strain gauges, and Figure 8 shows the designs according to which the simulation was performed. The simulation results are the relative deformations of the strain gauges, summarized in Table 3.

Table 3: Elastic element simulation results with strain gauges

Elastic element structure	Relative deformations of strain gauges at the air flow rate			
	5 kg/hour	100 kg/hour	300 kg/hour	600 kg/hour
Triangular	$2{,}49\cdot10^{-8}$	$8{,}271\cdot10^{-6}$	$7{,}273\cdot10^{-5}$	$2{,}888\cdot10^{-4}$
V- shaped 60°	$4{,}89\cdot10^{-8}$	$1{,}748\cdot10^{-5}$	$1{,}557\cdot10^{-4}$	$6{,}201\cdot10^{-4}$
V- shaped 90°	$4{,}906\cdot10^{-8}$	$1{,}751\cdot10^{-5}$	$1{,}558\cdot10^{-4}$	$6{,}205\cdot10^{-4}$

Comparing the data of Tables 2 and 3, we can conclude that the values of strain gauge relative deformations constitute 67-68% of the maximum relative deformations of a triangular elastic element and 52% of the maximum relative deformations of the V-shaped elastic elements.

Then the dependency curves of strain gauge relative deformation absolute value (figure 9) were developed against the mass flow rate of air.

On Figure 9, the red line denotes the values corresponding to the triangular elastic element, the blue line represents the V-shaped element with the angle of 60° and the green one represents the V-shaped element with the angle of 90°.

It can be seen from Fig. 6 that the absolute value of V-shaped elastic element relative deformation is greater than the relative deformation of the triangular elastic element of the mass air flow sensor.

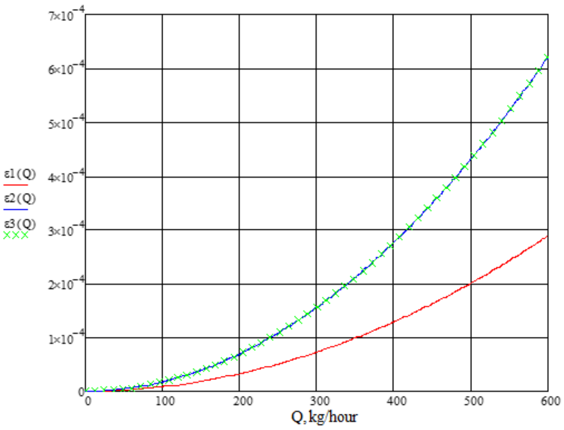

Fig 6: The dependence plot of strain gauge relative strain absolute value on the mass flow rate of air

4. Summary

The article describes the development of the computer model for mass air flow sensor converter using the SolidWorks and ANSYS software complexes. Three variants of the sensor transducer elastic element were described (triangular blade, V-shaped element with the angle of 60° and 90°). The simulation of the work is performed in the range of mass flow rates from 5 to 600 kg/h for each variant. Based on the results of the detailed simulation, it is established that the elastic V-shaped element with the thickness of 0.15 mm will provide the greatest sensitivity during the mass flow rate measurement.

Acknowledgments

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