COOKING BETTER AUTOMOTIVE SENSORS WITH COMSOL MULTIPHYSICS HELP

T. Gajdarus, M. Dubec, P. Žáček

Continental Automotive Systems Czech Republic s.r.o.

Abstract

Making right decision in the early stage of development can be very helpful and can save a lot of resources in the next development stages. Usual problem (everywhere) is to choose the best solution from few possibilities and taking into account all advantages and disadvantages. Comsol Multiphysics helped us in the sensor development with making such decision. We had to choose from two possible versions and Comsol pointed without building real prototypes for real test, which version can pass higher vibration load. In the next stage we could build samples of only one version and could concentrate on them much more. Later measurement with Laser Doppler Interferometer confirmed our simulations. The solved equation systems in this example were not very complex, but were (and still are) highly interesting from the commercial point of view.

Automotive sensors are in fact small plastic parts with integrated measuring element(s). They are much cheaper with the same level of accuracy compared to the similar industry sensors. Sensors in the car mostly improve safety, driving and engine performance, service costs etc. They are combination of the measuring principle, application area, used technologies and materials.

The main task of development is to create a sensor with parameters that best fit the customer's specifications and are as much cost effective as possible. Performance of the sensors according to the customer's spec. and planned lifetime is proven by Validation Tests. Representative group of sensors (for example 100) is passing complicated net of various environmental tests – i.e. durability tests (temperature shocks, salt spray test, vibration etc). All sensors must pass.

Example of T-MAP sensor is on the fig. 1 Sensor is used for measuring the amount of air incoming to the engine. Measuring of pressure in the engine intake tube is combined with measuring of air temperature. From these two values the ECU in the car is able to calculate exact amount of incoming air. This system of measurement increases the engine power and decreases engine emissions.

Figure 1: T-MAP sensor

The T-MAP sensor consists of two measuring elements. First sensing element of T-MAP sensor - the MEMS element is transforming applied pressure on the voltage output signal. MEMS element is always integrated with signal conditioning chip.

Second sensing element is NTC resistor with some plastic around for mechanical support. This part of T-MAP sensor is called "holder". NTC element is changing its resistivity according to the incoming air temperature. No signal conditioning chip is used.

Our task was to develop possible solution of holder with very low response time that meets the standard requirements for part mounted on engine (temperature, vibration, thermal & mechanical shocks, chemical robustness etc.). The response time is the time sensor needs to react on flowing air temperature change.

Fast response time requires small mass of the sensing element and good heat exchange with the environment (good airflow around NTC). This goes against request for mechanical robustness. Open light design are according to our experiences easily destroyable by vibrations.

Very nice series of articles about the designing vibration surviving products were published here [1]. One of the very basic rules is to keep the eigenfrequencies out of the product operating frequencies range. At the end we realized this rule was good enough for us.

Figure 2 shows existing holders in production. On the left side is standard holder that is joined to the most of T-MAP sensors and meets the most common specifications. On the right side is holder that was developed later to meet specific requirements for higher vibration loads. Both of them are using quite thick wires that provide sufficient support for the sensing element (the "pill"). Response time of those existing sensors does not meet some specific requirements for very fast sensors. That's why we made proposal of two possible fast holder versions. They are on figure 3. We called them B and C concept.

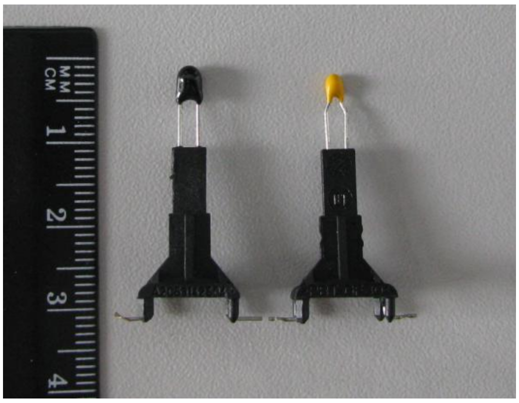

Figure 2: So called "holders" from existing production lines

The B holder design was based on some existing design of temperature sensor. The money investments in this case would be low due only few plastic molding tool changes. Similar concept is in the production now.

The plastic part of the C concept looks totally different. We expected the start up investment quite high (mostly because of buying the new prototype molding tool). But the results of response time measurements were more promising.

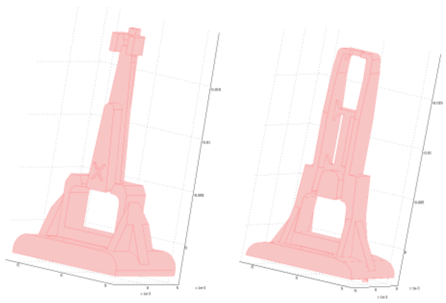

Figure 3: Next generation products proposal. On the left is concept B, on the right is concept C

The measurement of response time was done on the machined samples which were not suitable for the vibration test. For vibration testing the samples must be as much as possible close to reality (build by injection molding and attached with proper gluing etc.). That's why samples for the vibration test are quite expensive.

We made the simulations in order to determine which of these two concepts is better from the mechanical point of view.

We made simulations in 3D in basic Comsol Multiphysics module (Structural Mechanics -> Eigenfrequency analysis) according to the manual [2]. We calculated only eigenfrequencies of the holders, e.g. without any kind of damping. We wanted to compare the B and C concept. Leading idea was: keep the same material properties and compare the designs in vibration simulation. We did not expect perfect agreement we were looking only for some clues, but finally according to measurements the simulations were very accurate.

Meshing of the geometry input data was not critical. Example of used mesh is on the figure 4.

Choosing right material properties is one of the key simulation aspects. Wrong data buries the simulation and each literature source offers original values for material properties. As the input we used ordinary data from the internet [5] we found them most trustable. Finally we realized that input data were perfect.

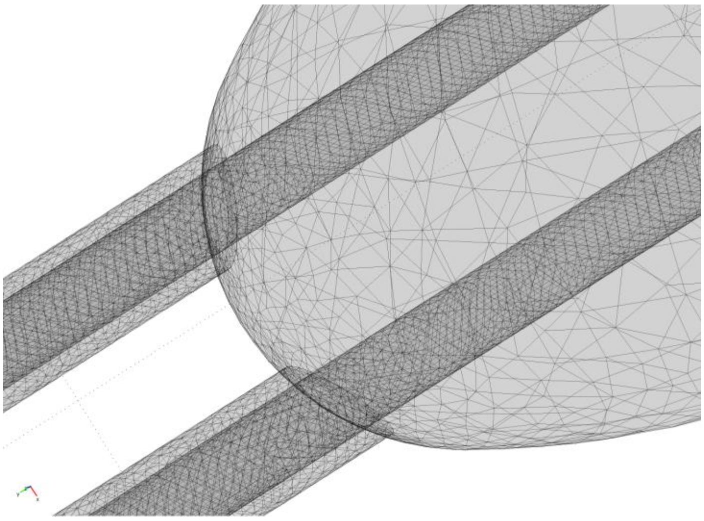

Figure 4: Detail of the used mesh

Each concept was simulated in 3.5 mm and 4.5 mm version. These were the lengths of the NTC head above the plastic (see figure 5). Higher versions have better response time but have also lower first eigenfrequency (rule of thumb).

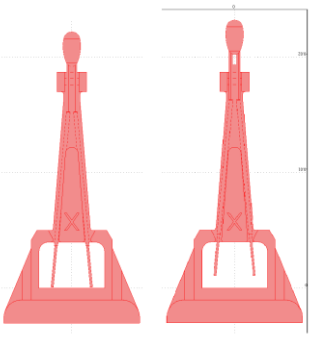

Figure 5: Concept B in 3.5 mm (left) and 4.5 mm (right) version

First vibration mode of holder is critical. According to our experiences we know that this is the killer in the vibration tests. Second mode is not critical, because is usually too high. 2nd modes were used for checking the theoretical results. Modes of C holder are on the figure 6.

Table 1 shows deviations between calculated and measured eigenfrequencies for the first two modes in [%].

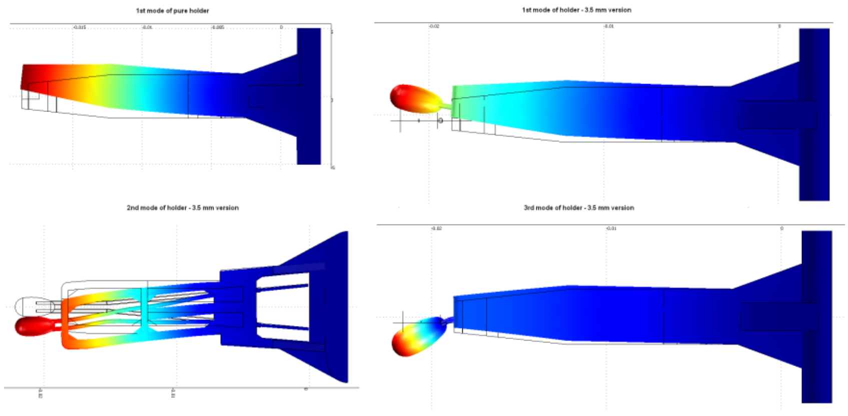

Figure 6: Vibration modes of C concept holder

Measurement was done with the help of Technicka Univerzita of Ostrava. It perfectly confirmed our simulations. Their laboratory equipment is perfect for our case (figure 7). Here is example of their work and equipment [3][4].

Figure 7: Vibration analysis equipment at TU Ostrava (different DUT – not T-MAP)

Table 1: Comparison of Simulation and measurement

Deviations Between Simulations and Measurements [%]		
	1^{st} mode	*2^{nd} mode*
Concept C - 3.5 mm	5	2.5
Concept C - 4.5 mm	-2.5	-20

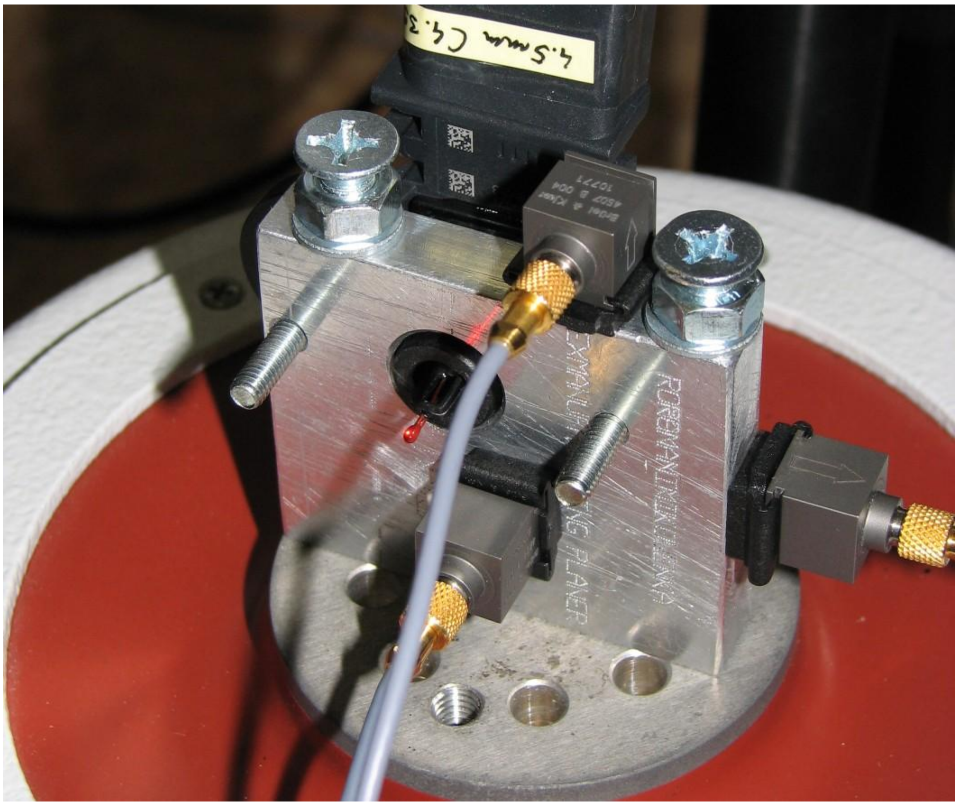

Figure 8: Detail of the measurement

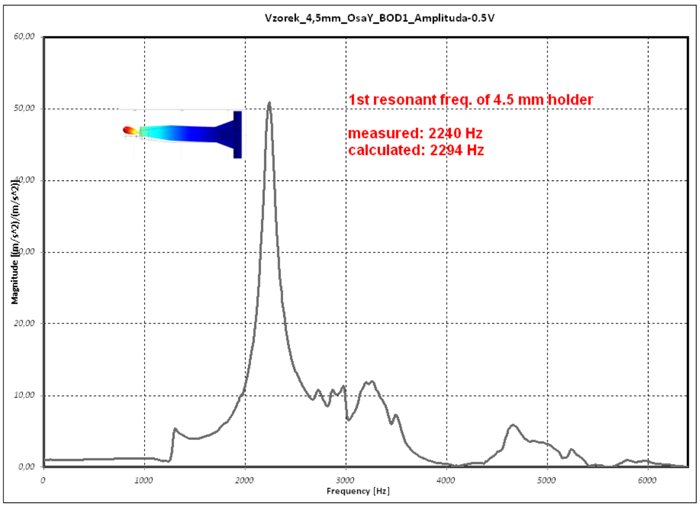

Figure 9: Example of FRF measured on the NTC's head

After taking into account all advantages and disadvantages concept C finally won. It has a lower response time and it has eigenfrequencies above 2 kHz.

This (still almost virtual) sensor can serve as a very nice example of development with use of FEM.

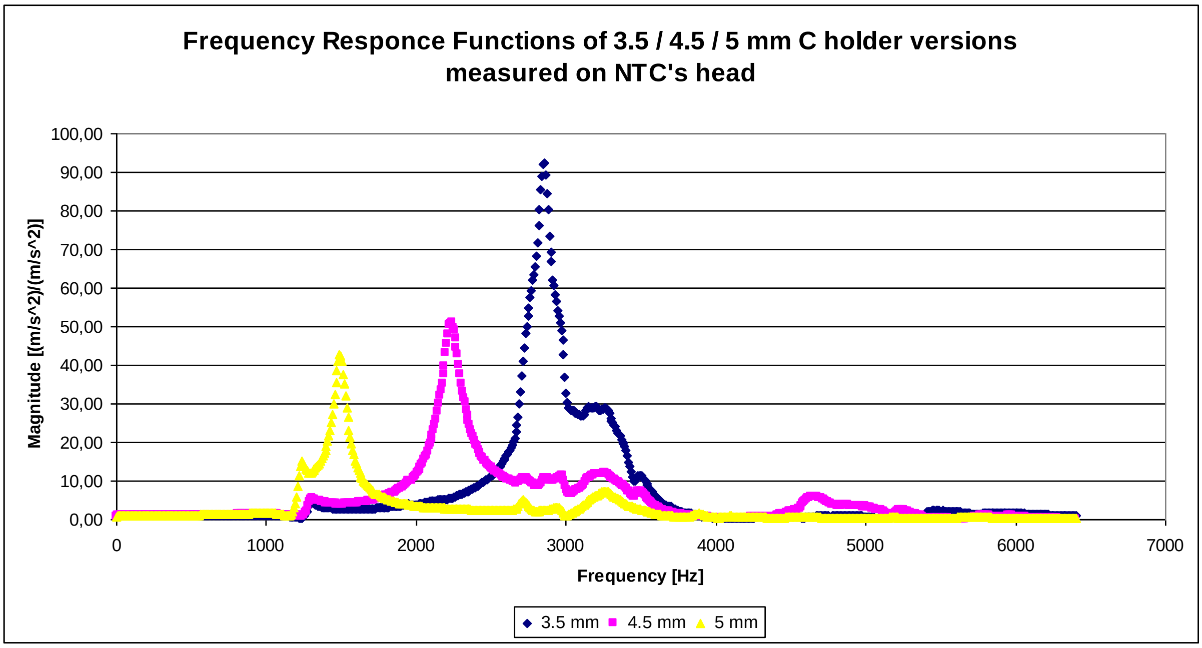

Figure 10: Resonant frequency is falling down when part is longer

References

[1] Linear Dynamics for Everyone, Part I, II, III, written by George Laird and published by Desktop Engineering, April – June 2008 (www.deskeng.com)

[2] Comsol User's Manual

[3] KLEČKA, R. & TŮMA, J. & QINGHUA WU Dynamics properties of sensors and actuators for a rotor test stand. In *Dynamics of Machines 2009*. Praha: Institute of Thermomechanics AS ČR, February 3–4, 2009, pp. 31-35. ISBN 978-80-87012-1.

[4] KLEČKA, R. & TŮMA, J. & MAHDAL, M. Analysis of measurement with TIRA vibrator. In *Proceedings of XXXIV. Seminar ASR '2009 "Instruments and Control"*. Ostrava: VŠB-TU Ostrava, 24. 4. 2009, pp. 22. ISBN 978-80-248-2011-8.

[5] www.matbase.com

Tomáš Gajdarus
Continental Automotive Systems Czech Republic s.r.o., Kopanská 1713, Frenštát pod Radhoštěm, tomas.gajdarus@continental-corporation.com

Miroslav Dubec
Continental Automotive Systems Czech Republic s.r.o., Kopanská 1713, Frenštát pod Radhoštěm, miroslav.dubec@continental-corporation.com

Pavel Žáček
Continental Automotive Systems Czech Republic s.r.o., Kopanská 1713, Frenštát pod Radhoštěm, pavel.zacek@continental-corporation.com