Impact simulation of a hearing aid

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Abstract

In the development of hearing aids, many factors are important to make a good hearing aid. It can be the sound quality, design and easiness of use. However, it is also important that the device can withstand the environment that it is used in, both regarding moisture, sweat and to be dropped on a hard surface. One of the most sensitive parts in the hearing aid regarding dropping the device on a hard surface is the receiver (name for the loudspeaker in the hearing aid).

The development of hearing aids demands shorter time to market and higher rate of success in achieving all the development requirements for the device. Therefore, it is important to be able to predict and improve designs in development projects.

In this case, a FE model of the hearing aid is built to predict the g force of a receiver inside the hearing aid, dropped from 1 m height. The simulated g force is compared to real drop test.

The FE simulations are performed in both Abaqus/Standard and Abaqus/Explicit in order to pre-bend some parts before they are imported in the impact simulation in Abaqus/Explicit.

The g force of the receiver during an impact are simulated with different designs of the soft suspension surrounding it.

Physical impact test with hearing aids containing the different suspension designs were performed and compared to the results from the simulations with good correlation.

Keywords: *Impact Simulation, Finite Element, Hearing Aid, Hearing Instrument, Industrial Application, Microphones, Receiver, Loudspeaker, Ear, Hearing, Life Science, Medical.*

1 Introduction

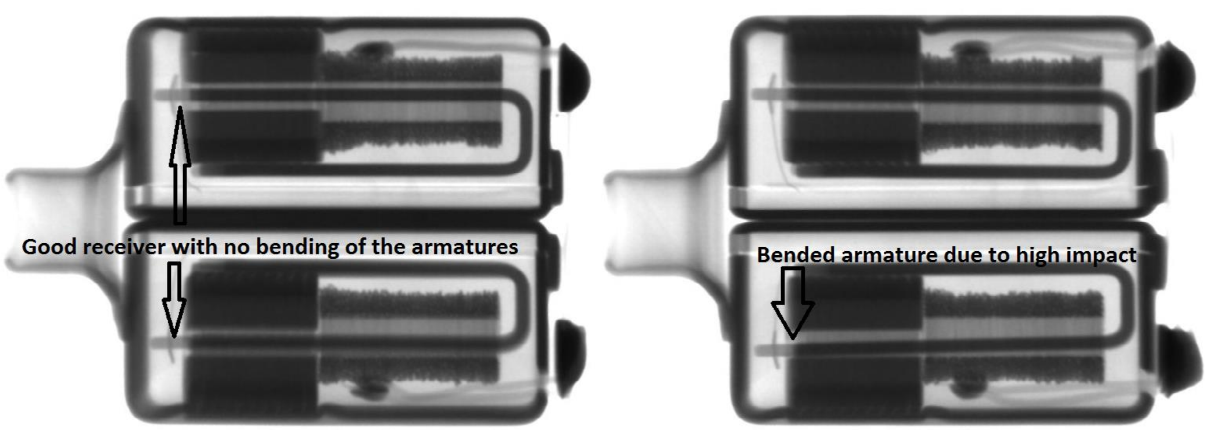
A hearing aid (in this case a BTE, Behind The Ear, instrument) comprises a microphone which receives acoustic signals. The received acoustic signals are processed where the processing may include amplification of the data. The processed signals are transmitted to a receiver (loudspeaker) of the hearing aid which converts the processed signals into another acoustic signal e.g. with a larger amplitude at certain frequencies. The receiver broadcasts this acoustic signal towards the tympanic membrane of a user of the hearing aid.

The trend for designing hearing aids is that the size is getting smaller to meet a more cosmetic appealing look and to reduce the stigma for being a hearing aid user. This leads to a smaller distance between the receiver and the parts and components next to it and thereby decrease the possibility of damping the impact force.

The most vulnerable component due to an impact is normally the receiver inside the hearing aid. The receiver is softly suspended, to prevent its vibrations from being transferred through the device and up to the microphones (in order to minimize feedback between microphones and receiver). The suspension around the receiver is usually made of rubber. The rubber suspension also helps to absorb an eventual impact when dropping the hearing aid on a hard surface.

The purpose of this simulation is to calculate the g force in the receiver when the hearing aid is dropped from 1 meter and landing on a hard surface.

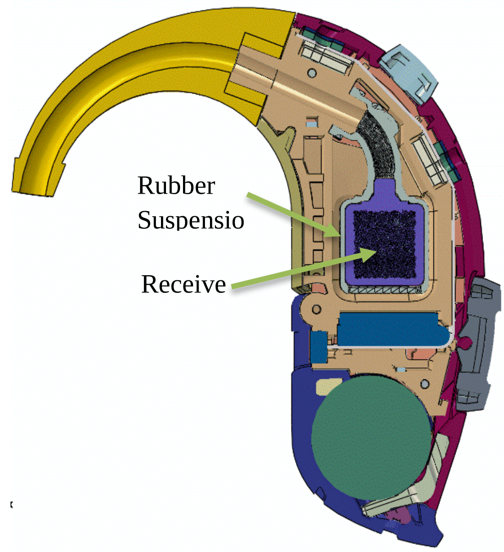
Figure 1.X-ray of good receiver to the left and receiver with bended armature to the right.



The supplier of the receiver specifies the g force that the receiver under investigation can handle as 14.000 g's.

As seen in in the right picture in figure 1, the armature /pin is bended due to a high impact. If the armature is bended, the receiver can still generate sound but it will be distorted. The impact damage of the receiver is detected by an electro acoustical measurement of distortion from the receiver.

Figure 2. Assembly of hearing aid impact model.



1.1 Advantages and benefits

The advantages from the simulations are that we can gain knowledge just from visualizing the impact and see where parts are moving and deflecting.
This increases the understanding of what happens during the impact, which we can use to improve the design and thereby durability of the device, which will benefit the user at the end.

Other advantages are that we can easily try out new designs virtually and save development time, because we exclude the time for drawing, molding, assembling and testing the next designs.

The physical impact test is a destructive test that only can give a pass/fail result and not provide the resulting g force. The simulation gives more explaining and understanding of what happens in the impact.

2 Description of finite element model

The simulation is divided in two simulations. First simulation will deform the receiver suspension to fit around the receiver. The last simulation is the actual impact simulation where the deformed suspension is imported.

The geometry for the parts are created in CREO and then imported as STEP files into Abaqus.

The material parameters for the plastic parts are from datasheet. The material parameters for the rubber is from mechanical testing of static stress-strain measurements as well as dynamic shear modulus (G’ and G’’).

The viscoelastic behavior for the rubber is changed from frequency domain (used in the pre deforming simulation in Abaqus/Standard) into time domain (using the frequency data) for the impact simulation in Abaqus/Explicit, (Abaqus Analysis User's Guide, V6.14, “22.7.1 Time domain viscoelasticity”).

2.1 Pre-deforming rubber suspension

The rubber suspension around the receiver is made smaller than the receiver in order to stretch the rubber, so it will hold the receiver inside it.

The rubber suspension needs to be in the deformed state for the impact simulation, else it will have overlapping geometry with the receiver.

This is done in a model run in Abaqus Standard in a Static General step with Surface-to-Surface Contact using small sliding and automatic shrink fit.

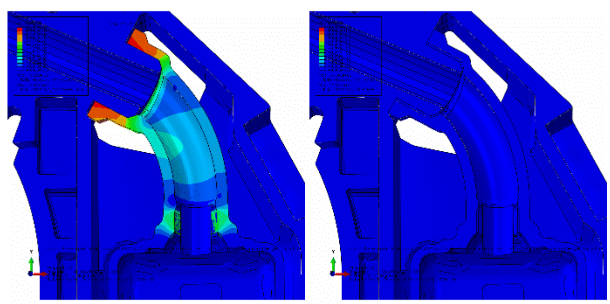


Figure 3. Pre-deforming of rubber suspension.

The undeformed suspension is shown to the right in figure 3. The deformed suspension is shown to the left, where the color map is indicating U (displacement).

2.2 Materials

The only deforming part is the suspension made of rubber. All other parts are made as rigid parts to make the model as simple as possible. In the future more parts will be changed to non-rigid, when we know more about their mechanical behavior regarding impact. A stepwise approach is proposed, where more and more parts are changed from rigid to linear elastic parts, and then later on changed to elastic-plastic behavior once we have the right material properties for this (requires material testing at the strain rate and corresponding strain). The contacts between the parts will also be changed from Tie to more appropriate contacts, which need to be investigated and stepwise applied.

3 Results and discussion

Several designs of the rubber suspension were simulated before actual design were manufactured and new hearing aid prototypes were built and tested.

Once the model is working, it can be used to simulate new and improved designs, much faster than producing new parts, building new devices, test them and compare the result.

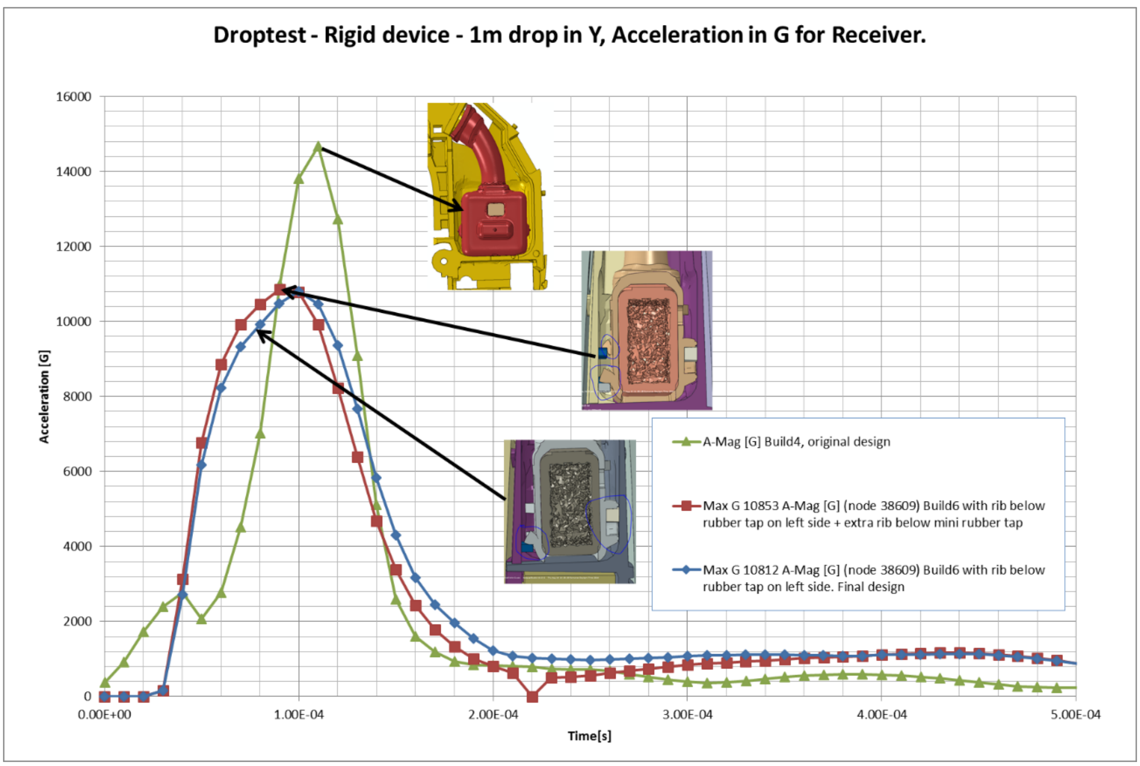


Figure 4. Simulated g forces on the receiver with different suspensions absorbing the impact

The results from the impact simulations made in Abaqus/Explicit are shown in figure 4. The original design, build 4, failed in the physical impact test when hitting from the bottom, Y direction. The simulation shows a maximum g force peak around 15.000 g's which is above the specified limit for the receiver which was 14.000 g's. The two other designs shown in figure 4 have added rubber taps in the suspension that are caught by corresponding plastic taps added inside the receiver chamber. These designs prevented the receiver in having a "free fall" and gave more impact absorption during the impact. The difference between the two last designs is that the final design, "Max G 10812" is not having the extra tab on the left side, because it did not give further impact absorption (as can be seen in figure 4).

The final design shown in figure 4 resulted in a maximum g force on the receiver around 11.000 g's which is below the specified limit for the receiver.

Subsequent physical impact test also showed that 10 devices built with the final design of the suspension passed.

The g force on the receiver was reduced from 15.000 g's of the original design to 11.000 g's on the final design.

Every time a new design of the rubber suspension was made and tested for impact, it was also necessary to make vibro-acoustic test on the devices to test for feedback between microphone and receiver. A good impact absorbing suspension will normally also have increased contact between the receiver and the surrounding of the receiver. The receiver vibrations will be transferred more strongly to the microphones, which will pick up the vibrations and send an electrical signal to the amplifier, and a feedback loop is created, (Søndergaard, 2009).

It is a balance to create the right receiver suspension for a hearing aid, because the impact criteria demands impact absorption material with contact to reduce the g force and at the same time the vibrating receiver must not have strong contact to the rest of the device due to transfer of vibration to the microphones. At the same time, the hearing aid should be as small as possible with small distance between all parts inside.

The final design of the rubber suspension was also tested for vibro-acoustic stability and passed.

Many other designs were also simulated, and in some cases it was possible to reduce the g force to 5.000 g's, but unfortunately they either failed the vibro-acoustic test or were not accepted by the project group due to mechanical constraints or time schedule (it would take too long time to implement).

3.1 Validation

The simulation will show the g force on the receiver. If the simulated g force is higher than specified by the supplier, we will assume it will not pass the physical impact test.

The supplier specifies a g force where their receivers in 90% of the cases will have less acoustic distortion (THD, Total Harmonic Distortion) than 10%.

The physical test at GN are performed by hitting 10 devices from all 6 sides as shown in figure 5. Each side is hit 5 times. They are hit by a pendulum that simulates a drop from 1 meters height. After each hit the THD of the devices are measured. If 9 out of 10 devices have less than 10% THD after the 6 x 5 impacts, then the test has passed.

Impact data from supplier (g force, 90% survival rate) are compared with physical impact test of devices and correlated with the simulated g force.

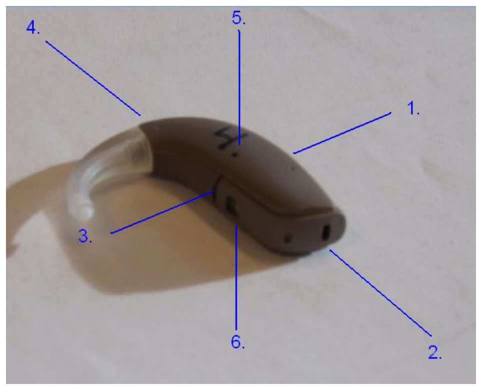


Figure 5. Impact directions on device of physical impact test.

Experiments with high-speed video recording (10.000 frames per second) of the physical impact have also been performed as seen in figure 6.

Figure 6. High speed video recording of impact. Left picture is 0.9 ms after impact. Middle picture is 0.1 ms after impact. Right picture is at impact.

The video recordings are difficult to interpret due to low image quality. It was however possible to determine that the receiver hits the inner wall of the hearing aid after 0.1 ms (middle picture in figure 6) which corresponds well with the simulations shown in figure 4. A picture of the hearing aid 0.9 ms after the impact is shown to the left in figure 6.

3.2 Assumptions

Other parts are made rigid to isolate the problem to the receiver suspension. We know that the plastic parts surrounding the hearing aid are providing damping for the impact.

Rubber material properties are changed from frequency domain to Time domain and we have not tested the rubber material for Mullins effect (permanent set when exposed for several impacts)

We also assume the device is hit exactly the same direction for the simulation as for the real impact test.

The simulation does not take into account if the friction force between the receiver and the suspension is strong enough to keep the receiver in place. We have seen some earlier dropt test cases where the receiver was moved from its original position after an impact. In the simulation, we have made a Tie between the suspension and the receiver, because we don’t know the correct friction between them. At the same time we also made test where the suspension was glued to the receiver to make a better comparison to the simulations with the Tie.

4 Conclusions

A FE model representing a receiver (loudspeaker) inside a rigid hearing aid was built in Abaqus/Explicit to simulate a drop from 1 meters height. The resulting g force on the receiver was derived from the simulations for different rubber suspensions surrounding the receiver. These results were both compared to physical pass/fail impact tests and to the manufacturer’s data for acceptable g force for the receiver. Good correlation was found between simulation results and tests. By using the approach described in this paper it was possible to design an impact protection that did not damage the receiver after impact and at the same time could fulfill the vibro-acoustic stability criterion.

5 Further work

We need to know more about the material properties in order to make more precise impact simulations, as explained in the section of assumptions.

The other parts that were made rigid should also be included to absorb the impact in order to give a more precise result.

6 Acknowledgement

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References

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