Efficient Sound Package Design Using Statistical Energy Analysis with Optimization Through Genetic Algorithm

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INTRODUCTION

In the last years, Statistical Energy Analysis (SEA) has evolved into a well-known analysis tool in order to simulate whole-vehicle acoustic performance at medium and high frequencies. This global approach makes SEA extremely valuable for making acoustic integration possible. It is outside the scope of this paper to describe once more the theoretical fundaments of SEA, as they have been sufficiently reviewed in various publications. As long as airborne noise is concerned, several authors have shown that SEA models can not just be used to match experimental data, but to improve vehicle performance by proposing adequate design changes [1-4].

Today the main challenge in the field of SEA (besides the structure-borne problem, which will be discussed later on) consists in speeding up the development of a model for a new vehicle program and in shortening the time needed per design iteration while maintaining the reliability of the results. This way, as many questions as possible can be addressed by the time when decisions are taken. This paper introduces one major improvement in the SEA vehicle acoustic modeling process: REALISE (Rieter hEuristic Algorithm for Lightweight Insulation through SEA), a procedure for Acoustic Package optimization based on Genetic Algorithms.

Optimization based on Genetic Algorithms

The whole process of defining an Acoustic Package demands thorough understanding of the materials that can be applied: performance, cost, industrialization, etc. Furthermore, it requires a feeling of where the acoustic package can be improved, where is it possible to reduce the amount of material, etc. Several attempts have been made in order to find the best possible compromise, focusing either on the material level [1] or on the component level [2]. Both approaches are complementary and yield different sorts of information. The work presented here focuses on yet a different level, whole-vehicle optimization, and complements recent development on the subject [3]. The name REALISE (Rieter hEuristic Algorithm for Lightweight Insulation through SEA) was chosen to denominate the whole procedure.

Once the SEA model of a vehicle has been fully developed and validated, it can be used to track down the main contributors of noise inside the passenger compartment. In the end, re-taking the idea of vehicle acoustics as a chain formed by links, the focus should be put in the weakest of them. This way, different solutions can be considered in order to improve the performance of the weak links and, eventually, reduce the specification of the strongest so that cost is also reduced.

The SEA optimization package procedure developed by Rieter Automotive and described here profits from these new possibilities by automating the process of inserting an acoustic package, solving the model and retrieving the results. It does not intend to replace the type of expert knowledge mentioned above, but rather to support it. It is still responsibility of the analyst to define the materials that can be applied together with a set of conditions (constraints) that the acoustic package has to fulfill and that are needed for a good definition of the problem. Afterwards, the software will do its job by systematically evaluating hundreds of different solutions according to specially adapted search criteria. The efficiency and validity of the whole procedure was satisfactorily verified.

Three main elements constitute the pillars of this optimization procedure:

a) A database with a set of pre-calculated transmission losses and absorption coefficients for multiple acoustic packages

b) An optimization algorithm based on Genetic Algorithms (GA)

c) A SEA model where the various packages can be introduced and their effect on the acoustic performance be determined

While (c) can be any given SEA model, (a) and (b) were specifically developed for this work.

Genetic algorithms, or search algorithms inspired by the principles of natural selection, have proven to be particularly well suited for complex non-linear problems [5]. As it will be shown here, that can be the case of whole-vehicle acoustic optimization problems, where due to the variety of materials that can be considered, not always the best performance can automatically be associated with heavier packages.

Two main features distinguish the proposed optimization method and influenced the choice and the structure of the search algorithm: the variables are not continuous and the search space is a multimodal domain (with multiple equivalent optima). Indeed, the algorithm handles discrete variables, each of them defining whether or not on a particular component a certain acoustic package is applied and, if appropriate, choosing a package type among a pre-defined number of possibilities. Therefore, the resulting objective function, which can not be directly determined, turns out to be irregular because of the variable definition. The benefit of using GA's to optimize irregular functions consists in that they perform a stochastic search over a large search space, using a set of solutions (so called population) that evolve together, instead of using one single solution as in other methods (as is the case of the Simulated Annealing).

The individuals forming this population (normally binary strings resembling chromosomes) go through a process of evolution. Some solutions are better than others in the sense that they have a higher fitness function value; consequently, they are more likely to survive and propagate their genetic material. In fact, the search performed by the GA's is guided by a scalar fitness function in which the constraints and the objectives of the optimization are combined. The convergence of the GA leads to a concentration of the population into regions of the search space where the fitness function presents a global optimum.

The creation of the 'children' population is done in three steps :

- Selection of two parents (random shot with probability proportional to the relative fitness of the solution in the population)

- Crossover of their chromosomes to create two offspring

- Mutation of the offsprings

Crossover and mutation are randomly applied. The selection operator is designed as a biased random process with high probability assigned to fittest individuals and low probability assigned to the least fit ones. As a result of selection, the average fitness of the next generation is expected to increase. Mutation is applied with a very low probability (inversely proportional to the chromosome length) so that few chromosomes are altered. Crossover is the exchange of genetic parts of different individuals. The scope of this operation is the search for useful information within the population; a single point crossover is the closest equivalent of natural phenomenon, but crossover variations such as two-point crossover and uniform crossover are also used in practice. Selection and Crossover favor the concentration of solutions having good fitness, thus attracting the population towards local optima. On the contrary, Mutation maintains the diversity of the genetic materials. The simultaneous action of these tree operators allows converging into a global optimum.

Once the optimization process is completed, either because the number of generations specified in the optimization script is reached or because the process is halted by the user, the results can be exported in ASCII format and post-processed using Excel. These results not only include the optimum but also all solutions that were calculated throughout the optimization process (up to thousands) and that can be conveniently filtered and sorted according to various criteria (performance, weight, material type or thickness in a certain region, etc).

Even when the optimum that was determined is valid only for the optimization problem as defined in the optimization script, useful information can be retrieved from the vast amount of solutions that were computed in the process. Thus, more restrictive criteria in terms of weight, applied materials, etc. can be used, yielding relevant information about potential of alternative solutions, expectable performance loss for a certain weight reduction, etc. Ideally, a new optimization process with the new parameters should be launched, but thousands of mostly good-performing configurations within realistic boundary conditions constitute a valuable source of knowledge.

Whole-vehicle optimization

For complex problems involving a large number of variables (or more possible values for each variable) the number of solutions rapidly increases to unmanageable figures. Even when for the example presented here some significant simplifications were made, it will be shown how optimization algorithms can satisfactorily be applied to whole-vehicle acoustic package optimization. For this purpose, it was taken a model based on one of the Rieter Template models. The acoustic properties (TL, absorption and pass-through performance of regions not subject to optimization) correspond to those previously determined for a vehicle available on the market. The acoustic loads, applied as constrained SPL around the vehicle, represent a certain case of purely acoustical artificial excitation (Engine Noise Simulator).

It was decided to consider six different regions where the acoustic package would be subject of optimization: headliner, upper and lower dash, front and rear floor, and package tray. In Figure 1, there is a summary of the material cases that were considered for each of these regions, including several conventional and Rieter Ultra LightTM configurations. Considering all possible combinations, this makes a total of 8.8.E+12 different cases (43 bits) from which the optimum is to be found by the optimization algorithm. The weight of the acoustic package can be directly derived from the material weights and areas where they are applied, which results in a lightest possible acoustic package of 5.7 kg and a heaviest of 44.5 kg. The objective function was defined in this case as the Sound Pressure Level in the range [630, 1250] Hz. The reason to proceed this way is that it was considered interesting to optimize the performance of the model in a frequency range where:

- The influence of airborne transmission could be assumed to be dominant (the SEA model used in this case was not conceived for structure-borne noise)

- The main acoustic paths (contributing to interior noise) correspond to treated regions

Moreover, it is advantageous to limit the number of frequency bands where the SEA model is solved as this leads to shorter computation times. In total, this optimization process took 11 hours to complete, processing over 7400 different configurations in 100 generations and with a population size of 80 individuals.

The load case and the frequency range where the package is optimized can have a significant effect on the type of solution found by the algorithm. In that sense, if a certain region does not belong to the main acoustic paths in that frequency range, it is more likely that a higher absorption coefficient will have a bigger impact than not having higher insulation, motivating that absorptive solutions will be favored by the optimization algorithm. Therefore, the optimization results will be valid for a specific problem only and should not be generalized without further considerations. It is also worth mentioning that this type of optimization procedures tends to stress any inconsistency present in the input model, yielding --if that is the case-- meaningless results.

The results (Figure 2) show in the case of our optimization problem that it is possible to save almost half of the sound package weight without compromise on the Sound Pressure Level.

Nevertheless, these results need to be interpreted carefully as two main issues restrict the applicability of this tool:

- Limitations inherent to SEA, especially in the scope of automotive applications, where, at least for the moment, predictive SEA models are just suitable for air-borne and not for structure-borne transmission. Experimental SEA models for structure-borne noise can help understanding where the acoustical problems are, but are barely suitable for studying design modifications. Mainly due to modal density requirements, the frequency range is limited to over 400 Hz.

- On the other side, the acoustic packages are assumed to have uniform thickness, which in practice means overestimating their acoustic performance

This last limitation will be easy to overcome in next versions of this optimization tool. Those strictly related to SEA remain a challenge that will require a substantially bigger effort.

Conclusions

SEA Optimization based on Genetic Algorithms can be used to maximize the output of Statistical Energy Analysis applied to vehicle acoustics. The necessary development time can be considerably reduced while at the same time dramatically increase the number of design configurations to be considered.

SEA Optimization based on Genetic Algorithms has shown how for any given region in a SEA model (sub-system or vehicle component) there can be defined a variability domain rather than a single value at a time. This makes possible to consider literally thousands of different packages, whereas previously it was just possible to examine a few. Search algorithms based on GA make possible to retrieve effectively the most interesting among all these possible configurations according to arbitrary constraints in terms of weight, performance, thickness or material choice. The whole procedure was satisfactorily validated using limited cases, for which the whole problem domain was known.

In essence, the possibilities of Statistical Energy Analysis are taken one step forward, putting the focus where it is important and combining it with efficient and flexible search algorithms. More meaningful information can be made available at earlier stages of a vehicle program, which is to say more and more valuable information.

References

1. B. Semeniuk, Optimization, in Particular as Applied to the Acoustic Performance of Automotive Trim Components, Proceedings of 2001 Rieter Automotive Conference, June 2001.
2. R.G. DeJong, *Optimization of Vehicle NVH Design Using SEA,* Proceedings of Internoise 2002.
3. J. Pan, B. Semeniuk, J.R. Ahlquist and D. Caprioli, Optimal Sound Package Design Using Statistical Energy Analysis, SAE paper 2003-01-1544, 2003.
4. C. Bertolini, L. Gigante, *An SEA-based procedure for the definition of sound-package component targets starting from global vehicle targets*, Proceedings Vibro-Acoustic Users Conference (Europe), 2003.
5. D.E. Goldberg, *An investigation of niche and species formation in genetic function optimization*, Proceedings of the Third International Conference on Genetic Algorithms, 1989.

Figure 1:

	(A) Material Types	(B) HL/AFR cases	(C) Decoupler Thickness cases	Possible Combinations (A)x(B)x(C)
Headliner	1	1	4	4
Dash Upper	4	16	8	512
Dash Lower	4	16	8	512
Floor Front	4	16	8	512
Floor Rear	4	16	8	512
Headliner	2	16	1	32
TOTAL				8.796E+12

Figure 2 :