

Parameter Design Based FEA Correlation Studies on Automotive Seat Structures

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ABSTRACT

In recent years, the design of automotive components and assemblies have resulted in an over-reliance on advanced CAE tools especially the Finite Element Analysis. An emphasis on cost reduction and commonization of components in automotive industry has made it necessary to use the CAE tools in innovative ways. Use of FEA as a effective product development tool can be greatly enhanced if it provides a high degree of correlation with physical tests, thereby greatly limiting the investment in expensive prototypes and testing. This paper will discuss a robustness based methodology to realize effective correlation of finite element models with actual physical tests on automotive seat structure assembly, at a component , sub-system, and systems level. Based on a parameter design approach, the various factors that affect the degree of correlation between CAE models and physical tests will be described. The application of this methodology in developing cost effective automotive seat structures will be discussed and recommendations for future study will be made.

INTRODUCTION

There is an ever increasing demand for using innovative and cost effective designs in various automotive components and assemblies. One of the most commonly used design and analysis method in automotive field is the Finite Element Method. This method has been used very effectively during the early stages of product development life cycle to understand the strength and weakness of a design thereby serving as a effective prediction tool. This method together with other simulation tools, collectively known as the CAE tools has resulted in more cost effective designs and faster delivery of the product to the market [1].

In recent years, the global competition in automotive business has resulted in searching for innovative ways to reduce the product development costs. For many years, the CAE methods were used as a validation tool,

reinforcing the results obtained in a physical test. This scenario is quickly changing, and there is a greater emphasis on using CAE as an effective design and validation tool, substituting the real physical test to the maximum extent possible. This new thinking is based on the expectation that the quantities of prototypes used for test and cost of testing could be minimized, with a greater reliance on the CAE methods and tools [2]. This requires that there is a clear understanding of the CAE methods and there should be a very high degree of correlation between the CAE simulation and real physical test.

Many different correlation methods that would explain the results of the CAE analysis to actual physical tests have been reported [3, 4]. The correlation of CAE results with physical tests have been very consistent in component level, but the system level designs have various factors that make the correlation of FEA results with actual physical tests very challenging.

Physical testing has been used downstream in the product development process to validate the design before releasing it to manufacturing. As it moves upstream into the product development process, it could serve as an effective method to characterize design and to correlate simulations.

This paper will discuss an effective method to determine the key parameters that could be used as effective candidates for correlation tests. The factors that affect the correlation of physical tests and CAE simulations will be studied with greater emphasis on a system level. The results of the study would be used to understand the issues that are inherent in physical tests, and methods in CAE simulations that could compensate for the differences between the physical test and CAE boundary conditions.

SYSTEM SIMPLIFICATION APPROACH

Automotive seating systems are one of the most complex and demanding systems in the vehicle. The

seating system has to satisfy a host of load cases, that includes fatigue loading, quasi-static loading, vibrations, and crash impact loading. The magnitudes of the loads applied to the seat structure generate stress and strain levels that are in the non-linear region of the material behavior curve. This creates additional challenge during the CAE analysis and demands an extensive review of various contributing factors.

The automotive seat system consists of three main sub-systems, and many other components. The components can be another system themselves, based on the function and complexity of the part. The fundamental function of an automotive seat system is to provide a safe and comfortable position for an occupant of the vehicle. The seat systems can offer many different configurations and functions as demanded by customers. The main architecture of many automotive seat systems consists of a seat back frame assembly, seat cushion frame assembly, and the riser or pedestal assembly. They are interconnected with each other with fasteners, and are available in many different types of connections with widely differing degrees of freedom. The load transfer occurs from the occupant to the vehicle floor structure through a complex interchange of energy from the seat back frame, cushion frame and riser structure, with the joints serving as the key conduits for the energy transfer.

Many of the seat back frames and the cushion frames are assembled together with another sub-system such as the recliner mechanism or folding latch mechanism. The mechanism itself is a complex sub-system, and in some cases can be the most complex part of the seat system. Similarly, the cushion assembly and the riser/pedestal assembly are assembled together with another sub-system between them called the seat track/slide assembly. The cushion assembly can also be linked to the seat back frame and riser/pedestal using the popular four bar linkage or one of its derivatives. Besides these structural assemblies, automotive seats have foam and plastic interfaces along the load path that do not play a significant role during occupant load transfer mechanism.

The analysis of the complete system not only becomes quite time consuming, but also the cumulative errors propagated through the system interfaces can result in non-optimal solutions. The FEA simulation should reflect the real world application and be conservative in the approach towards loading assumptions in order to achieve a high confidence in the resulting solution. One of the major advantages of using FEA in automotive design and development is to understand and discover the failure modes well in advance along the product development life cycle. The reliability and robustness of the simulation are highly important if the FEA is to be used in place of physical tests, as is the aspiration in the industry today [5]. This requires that the FEA simulation must be performed with a good understanding at the systems level, and it optimizes the entire process

by breaking down the analysis into sub-systems and component levels. The testing done on sub-systems and components are more cost-effective and has a better correlation with physical tests due to reduced number of interfaces. The FEA simulation on the sub-systems and components are usually performed by different suppliers/vendors, and the system integrators would again perform a complete seat system FEA simulation on a hard bedplate. Upon qualification of the requirements on a hard bedplate, the FEA is performed with the seat system in the vehicle environment.

The seat system is one of the most expensive assemblies in a vehicle. The development cost of seating systems could be greatly reduced using CAE tools like the finite element analysis. As previously mentioned, cost of physical hardware testing and failure mode discovery at later program stages in complex systems could have significant cost impacts. Cost of developing countermeasures during the physical testing of prototype is high, as shown in Figure 1. This situation could be an opportunity for the using CAE methods to effectively predict the design flaws even before building the first prototype tool. Efficient use of CAE could be made at the design development stage, including correlation physical tests, to avoid expensive physical validation tests later in the product development stages.

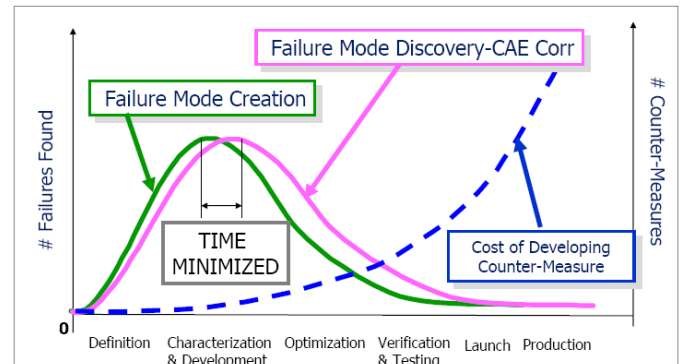


Figure 1. Schematic showing the effective use of CAE and correlation tests in the early stages of product design.

The traditional use of CAE methods have always been to verify the design, and there has been some level of skepticism on relying completely on CAE solutions for design verification instead of using data from actual physical tests. Various factors influence such an understanding, including the lack of knowledge on the micro-mechanics of FEA by product developers. The FEA simulations are performed by specialists and unless the product developers work closely with them maintaining constant communication on real world boundary conditions, manufacturing limitations, modeling constraints and material property information, there would be a chance to make an error towards completing a proper analysis. The use of CAE tools, particularly FEA has been misunderstood as a solution for design

verification along with prototype testing instead of using it as a tool for design development. The other most important aspect of using the FEA as an effective tool is the confidence in the analysis results. The simulation of the design using FEA needs to be verified with a actual physical test with a small sample size. These tests are commonly known as correlation tests, and are highly recommended before the initial mass produced prototypes are built for verification testing. The FEA simulation must show a very high degree of correlation with the physical test in order to predict the validity of future design changes. Unless this is proven with good reliability and accepted by the product developers, the full benefits of using CAE as an effective tool would always be questioned.

The less complex the system to be simulated using CAE tools, the higher the robustness of the results. As previously mentioned, one of the effective ways to manage the system complexity is to use system simplification, where a system is broken down into sub-systems and components. The FEA simulation can be independently performed on the components at the early stage of the design development, and the completed and verified model could be provided to the next higher sub-system for further analysis. The complete seat system model would then be simulated and analyzed on the hard bedplate. Finally, the seat system is validated for the input energy requirements at the vehicle level, which would provide the systemic results.

CORRELATION TESTS

One of the most important drivers for using the CAE tools is the reduction in the number of physical prototypes that are typically used to qualify a systems design. The use of FEA simulations of physical tests is an important strategy that would result in a reduced quantity of physical test samples that are very expensive in prototype stages. This requires that the results of the physical test and the FEA simulation are very much in agreement each other, and any deviation can be objectively explained. This "correlation" between the CAE simulation and physical test must be clearly understood and quantified, both in magnitude and direction. The percentage deviation of the measured output between the CAE simulation and the physical test can be termed as the "Error Percentage". The complement of the "Error Percentage" is the degree of correlation.

There are various factors that would contribute towards the correlation of a FEA simulation with an actual physical test. Though these factors were studied for the application in automotive seating systems, they would still apply to any system with similar loading and constraints. There are variations in both the FEA simulation modeling, and physical testing. We would explore the factors in more details to understand their

contribution and make informed decisions. These factors can be better understood using the robustness principles, including the use of the 'Fishbone' diagram, as shown in Figure 2.

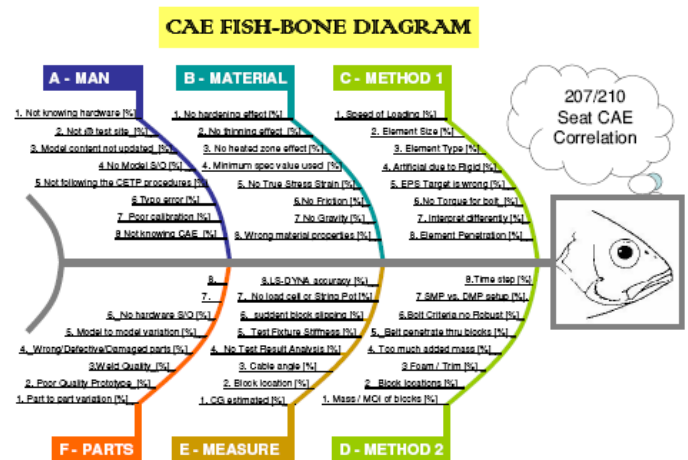


Figure 2. Schematic showing the "Fishbone" diagram of the CAE method to simulate the quasi-static loading test of a seat system.

Some of these factors are:

1. The welding between structural components are assumed perfect. The models do not reflect additional material or the effect of heat affected zone of welding.
2. The bolted connections transfer energy at 100% efficiency. This is not true in a real test since the bolted joints dissipate energy due to inherent friction, and various other micromechanics of bolted joints [6].
3. The thickness/gages of the structural parts are at nominal. This is due to the FEA models being generated off the CAD models that are drawn at nominal dimensions. The real world samples may be different from the nominal dimensions.
4. Material properties assigned to FEA models are at their minimum values. In real physical parts, the material properties may be different due to raw material manufacturers' variations, as well as the changes in material properties due to the effect of forming operations such as stamping.
5. The constraints used in the FEA models may not match the d.o.f of the actual test sample. Though the FEA model mostly takes care of this issue, what happens in reality can be understood only after the first physical test is completed. This would pertain more to a new type of design without any prior history.
6. The selection of an element type may have an effect on the strain values. In areas of excessive structural deformation, the element types must exhibit higher order equations to