

MULTIDISCIPLINARY SPOTWELD OPTIMIZATION USING OPTIM WELDS

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ABSTRACT –

Welding is an essential part of any automotive assembly but determining the proper placement of welds can be a time consuming and difficult process. At the same time, there is a strong need to decrease the overall number of welds in automotive assemblies to reduce manufacturing cost and time without sacrificing structural integrity. The current spotweld optimization procedures used today involve much trial and error and are typically limited in capabilities. Optim Welds, a multidisciplinary FEA spotweld optimization tool developed by BETA CAE Systems, USA allows engineers to efficiently optimize the locations of spotwelds, including non-uniform weld distribution, on an assembly while also saving time and resources compared to current optimization approaches. Starting with a running FEA model, Optim Welds guides the user through the entire optimization procedure. Tools are provided to easily create and parameterize spotweld lines, while an optimization workflow is automatically generated according to user inputs. The resulting optimization is capable of handling multiple loadcases, disciplines, and solvers simultaneously, with the user being able to freely choose their preferred finite element weld representations. Non-uniform weld distribution is achieved through flagging critical welds in the model according to a user-specified threshold criterion, which are then carried over to subsequent designs automatically. Weld lines are parameterized in groups, leading to a reduction in the number of design variables and total optimization time. At the same time, the use of critical welds strategically places welds in important locations. Model symmetry can be defined to ensure weld placement is feasible for production. A case study with a simplified vehicle model using frontal and side crash loadcases was performed. Results after 77 designs showed a reduction of 270 welds (4%) while still meeting performance targets.

1. SPOTWELD OPTIMIZATION PROCESS OVERVIEW

The current approach to optimizing weld locations is one that is lacking proper capabilities. The functionality is limited, and typically involves a tedious and time-consuming process of manual trial and error. Although spotweld lines can be used in combination with an optimization software, this still requires many designs to converge on an optimum, and pre-processing software currently only allows uniform spacing for weld lines, which may not be ideal for every assembly. Overall, the process is inefficient and ultimately leads to higher production cost and manufacturing process delays due to poor placement of welds. Optim Welds is a user friendly, guided, and robust tool within the ANSA pre-processor that will allow engineers to efficiently optimize the location of spotwelds on an assembly while also saving time and resources compared to current optimization approaches.

With this tool, we can take a current assembly with many uniformly spaced welds, and find an optimal, non-uniform distribution with fewer welds that still meets performance targets.

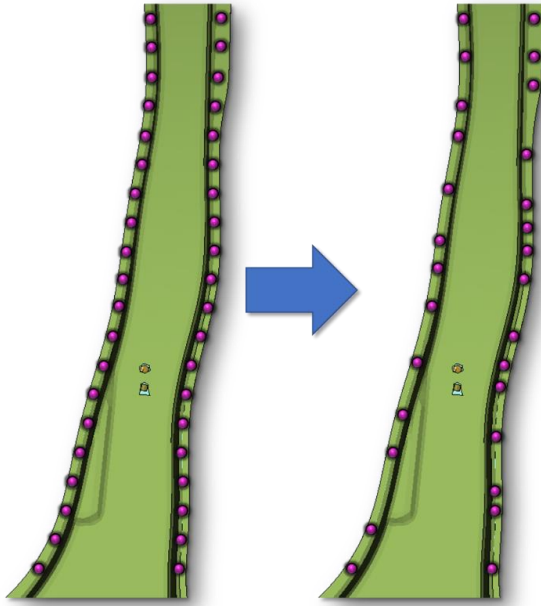


Figure 1 – Schematic representation of initial and optimized weld distribution of a B-Pillar

Taking a running model and one or more loadcases, Optim Welds will guide the user in finding an optimal distribution of welds on their model. The main advantage of our tool over a standard spotweld line optimization is the capability of creating non-uniform weld spacing, allowing for a more efficient placement of welds. This non-uniform spacing is accomplished through retaining welds that are critical to the performance of the model, while also varying the weld pitch using spotweld lines.

Optim Welds is designed to handle a multidisciplinary design optimization and can be used to optimize multiple loadcases of the same model at once. Naturally, this means that common connections between these models can have different weld element types and materials. There are no restrictions on the welds that are used for the optimization; the only criterion is that the welds be capable of being post-processed individually.

Using critical welds, we can reduce the number of design variables used in the optimization, leading to a reduction in simulation runs needed before an optimum design is found. All of this is accomplished through the Optim Welds user interface within ANSA, which uses a streamlined approach to quickly prepare the model and to extract the results of the optimization.

We've taken steps to ensure the designs created during the optimization would be feasible in production. This includes allowing the user to specify a value for the minimum distance they would like between their welds to ensure the design is manufacturable. Additionally, weld lines can be marked as symmetric, which ensures the weld locations for symmetric parts are always mirrored as they would be in reality.

In case there are any welds that are deemed necessary for production of an assembly, these welds can be set as manufacturing welds that will remain at a specific location throughout the optimization. A main goal in the development of Optim Welds was to allow the user to freely model their loadcase as normal, without restrictions on weld representation or sheet stack-up.

2. OPTIMIZATION MODEL PREPARATION

The Optim Welds interface is built as a plugin inside of ANSA and is designed so that the entire weld optimization process can be completed from start to finish without ever having to leave the ANSA window. Its lightweight design makes it easy to quickly prepare and optimize a model, whether it's a small assembly or full vehicle.

The Optim Welds GUI is divided into three sections to facilitate the spotweld optimization process. The first section, Model Setup, is used to prepare the initial model for optimization. Next, the Loadcase Setup tab is used to specify the necessary optimization case files and constraints. This information will be collected and passed to the optimizer software, which is then executed from within the tool. Finally, the Report tab will monitor the progress of the optimization and report back to the user the current best designs.

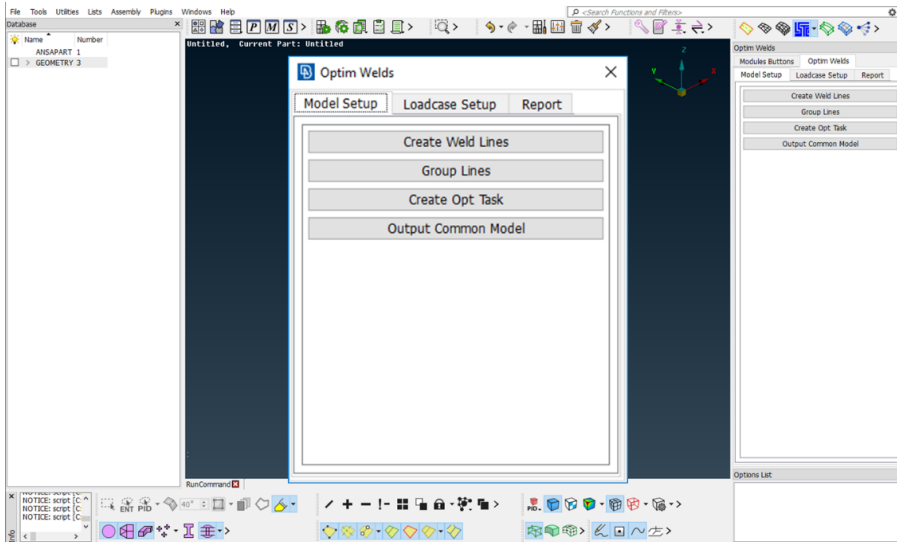


Figure 2 – Optim Welds user interface within ANSA

In the model setup tab, there are 4 tasks which are performed sequentially by the user.

The first function is “Create Weld Lines”. As mentioned previously, spotweld lines are used to facilitate the spacing and creation of welds on the model and are necessary for the Optim Welds optimization to be performed. The “Create Weld Lines” function allows the user to easily convert any existing spotweld points in the design space to spotweld lines while maintaining any connectivity that is already defined.

Next, the “Group Lines” function is used to assign multiple spotweld lines to a group so the line spacing of the group can be varied by a design variable. It is at this stage that weld lines are defined as being used for optimization; any lines not part of a group will keep their baseline spacing and won’t be optimized.

The selection process is left to the user, but it is recommended that lines be grouped according to location on the model. In this way, the optimizer can better understand how the loads are being handled by the welds at those locations and can control the spacing of the lines more effectively. Additionally, there is an option where these groups are split according to a line length value. This extra step allows any shorter lines to be spaced independently of relatively longer lines, the value of which may be driven too high for short weld lines to realize welds effectively.

Once all relevant lines are grouped, the “Create Opt Task” function can be used to automatically generate the ANSA Optimization Task that will be used during the optimization loop. The grouped lines defined earlier are then assigned a design variable for their respective groups.

Finally, in the case of an MDO, a common connection model containing the created lines, groups, and Optimization Task can be transferred to other loadcase models via the “Output Common Model” option. In this way, the previous three steps do not need to be repeated for any other models. This will also ensure that the models always have the same welds at the same locations for each loadcase and are consistent during the optimization.

With the baseline model complete, the next tab focuses on defining the optimization loadcases. Here, the user will select the relevant optimization information such as model files, submission command, META Post session file, and constraints.

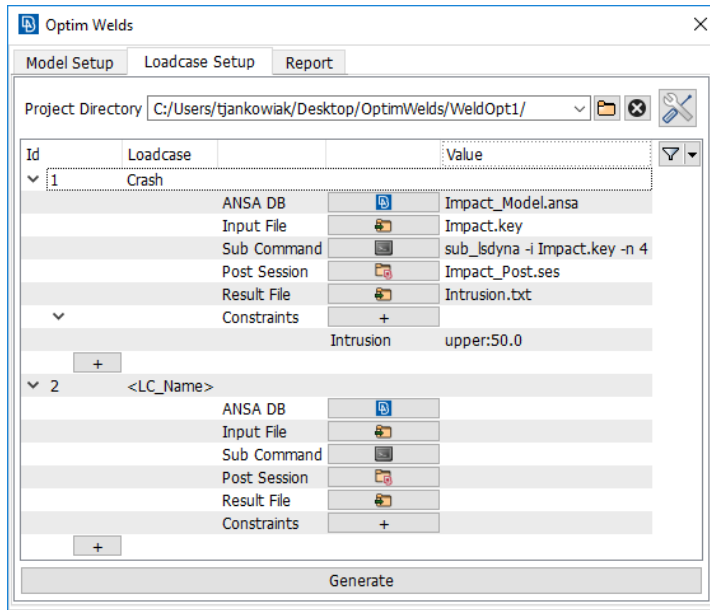


Figure 3 – Optim Welds loadcase setup window

By default, the objective is set to minimize the total number of welds in the model; this number is automatically captured in the background for every design. Constraints and loadcases are both handled dynamically and can be expanded as needed for the specific optimization case. The information provided will then be used to automatically generate an LS-Opt project file, which will be used to drive the optimization. With the project file created, the optimization can be executed through the Optim Welds interface while it is performed entirely in the background.

The last tab for the optimization process is the results tab, where the best designs are dynamically reported within the Optim Welds GUI.

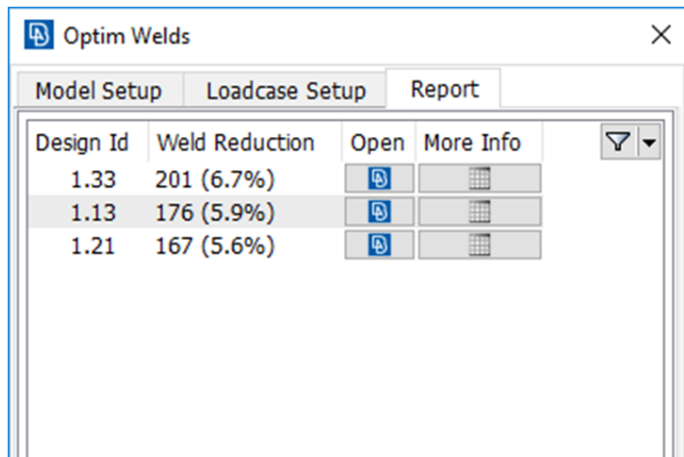


Figure 4 – Report window showing best optimization designs

Only designs that satisfy the optimization constraints while also having a reduction in welds will be listed, so failed designs do not need to be filtered. The design ID as well as the number and percentage of welds reduced from the baseline are shown in the window, so the user can easily see how the optimization is progressing. Once a design has finished that satisfies the user, the optimization can be stopped and the optimum model can be imported into ANSA for inspection. Additional information regarding the run, such as constraint values or total number of welds, can be seen through the button labelled “More Info”.

3. OPTIMIZATION CASE STUDY – REDUCED VEHICLE MODEL



Baseline Design		
Number of Welds	Front Intrusion (mm)	Side Intrusion (mm)
7094	64.7	195.7

Figure 5 – Vehicle crash models and baseline constraints

To demonstrate the capabilities of Optim Welds on a large scale, we performed a case study using a simplified vehicle model with two crash loadcases. It was important for the study to use at least two competing cases to ensure the tool would be robust enough to handle a multidisciplinary optimization. Like it was shown in the Model Setup tab, we converted spotweld points into lines that would then be used in the optimization. For optimization constraints, we set the baseline intrusion values for these designs as the upper limits, with the goal being a reduction in the total number of welds in the model without sacrificing our baseline performance.

As explained earlier, it's necessary for weld lines to be placed into groups prior to starting the optimization. We created 16 groups of lines, selected according to their location on the vehicle. For example, the spotweld lines for the front doors are selected together in one group and marked as a symmetric definition for weld creation. The groups are then separated into two based on the length of the spotweld line. Once grouped together, these lines will all be assigned a single design variable for the duration of the optimization. The design variables themselves control the pitch of the line which will be a different value for every design according to what is calculated by the optimizer.

With line parameterization completed, the common connection line model, along with the ANSA Optimization Task, can be output as a database to be merged with any other loadcases that will be a part of the optimization. With common connections in all models, we can be sure that the spacing and subsequent placement of critical welds will always be consistent across the models we're optimizing. With the models prepared, we can then move to the "Loadcase Setup" tab where we provide the information needed for Optim Welds to automatically create the optimization workflow.

Currently, the optimization process in Optim Welds is controlled by the LS-Opt engine which will need to be installed separately from Optim Welds. However, the tool is not limited to using only LS-Opt and can be developed to couple with other optimizing software. The design variables created while grouping the lines will be transferred to LS-Opt and varied according to its own algorithms. This will in turn change the spacing of the lines in every model while any critical welds that have been flagged in the previous designs will be carried over to all loadcases.

The change of spacing and weld realization all occurs on the base file prior to the output of the deck file. Once the model is solved, both the weld criteria and any constraint

responses are extracted through the META session file, where the relevant information is passed to the Optim Welds plugin and to the optimizer.

The optimization itself progresses iteratively with a parameter domain reduction occurring after enough designs have passed, followed by more sampling points. With enough designs, the spacing of the line groups can be narrowed towards an optimal value until the user has found a design that satisfies their weld reduction criteria.

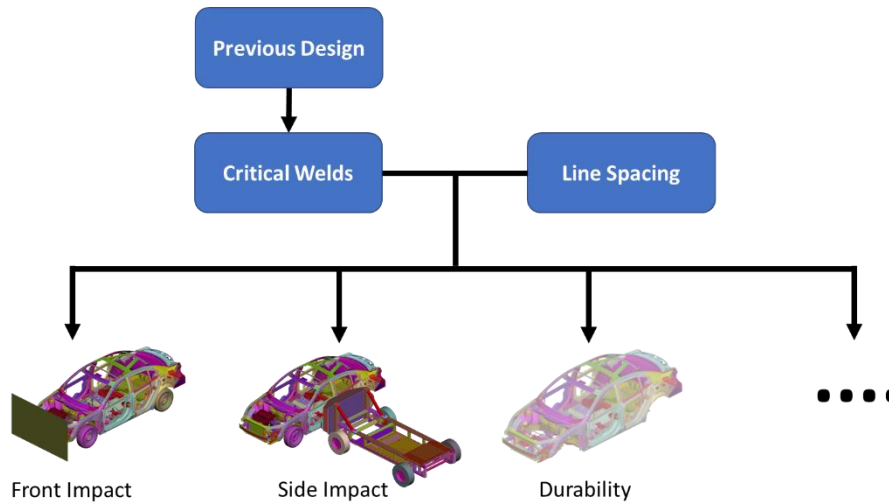


Figure 6 – Spotweld commonizing across loadcases for MDO

Optim welds fully supports the use of different disciplines and solvers for optimization. The tool can handle any number of loadcases and loadcase combinations as is needed by the user. This also includes models with dissimilar meshes and connections. If you are performing an optimization with a combination such as crash, durability, and NVH loadcases, you will be able to use whichever weld type and material that is typically used for those individual disciplines across common connection lines.

With the intelligence of Optim Welds, if a weld is determined to be critical in a crash loadcase, that critical weld will appear not only in the following crash design, but also the durability and NVH designs with its correct weld type and connectivity. The weld information provided through the connection manager of the individual base models will be responsible for controlling the properties of the weld that is created.

Critical welds are the most important aspect of the Optim Welds process. As touched on before, these are welds that are deemed important to the model according to a user-defined criterion that is processed through META. This criterion can be anything that distinguishes a weld as taking a significant amount of loading during the simulation, whether it's force, stress, material failure, etc.

In this simplified vehicle test case, we chose a beam force of 6000 newtons as our critical weld threshold. When a weld passes this threshold, it will be flagged and subsequently carried over to the following design automatically while keeping the same connectivity and respecting any symmetry that was defined in the setup stage. This includes not only the loadcase which flagged this weld, but also any other loadcases that are a part of the optimization. If, during the next design, this critical weld no longer passes the threshold, it would not be carried over again. The weld tolerance value set earlier ensures that this critical weld and any weld realized through a spotweld line will not conflict and overlap with one another. With this intelligence combined with the varying of spotweld pitch provided by the optimizer, an optimal, non-uniform distribution of welds can be achieved.

In the case of our vehicle models, the results were post-processed using the META IHS Toolbar with a focus on the front and side intrusion values for their respective loadcases. These intrusion values were then used as the constraints for the optimization. A separate section of this META session file is then responsible for processing the results of

every weld for determining which welds are critical. The specific constraints and weld criteria that are used is left up to the user to decide based on their needs.

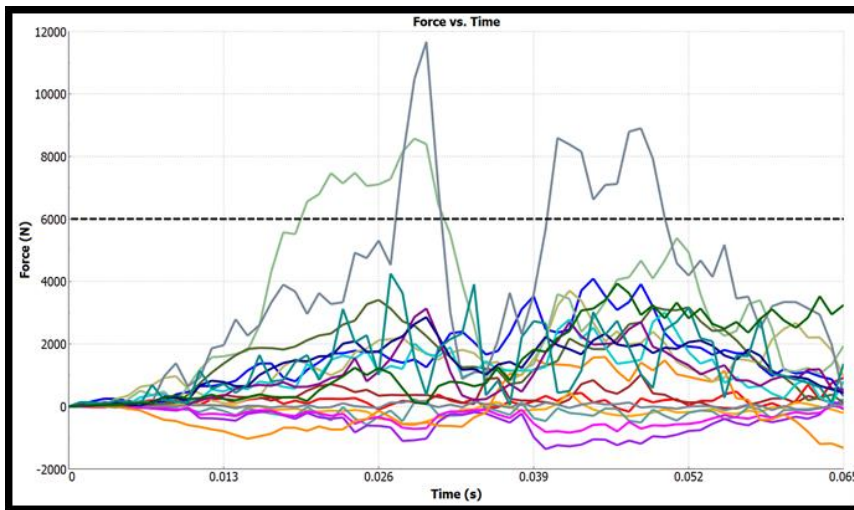


Figure 7 – Weld axial force vs. time with critical weld threshold at 6000N

For our case study, critical welds are any beam elements that pass an axial or shear force value of 6000 Newtons. Therefore, we plot all beam force time history data. The absolute maximum force value for each beam element is then extracted. In Figure 7, we have two welds that cross this 6000 Newton threshold. Optim Welds will mark these welds as critical and they will carry over to the next design in the optimization.

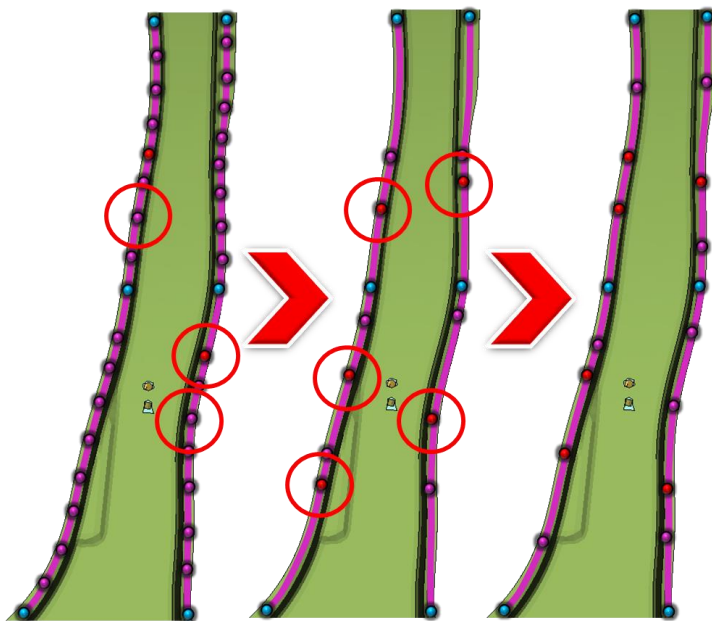


Figure 7 – Schematic representation of optimization progression with B-Pillar. Critical welds are circled in red

7. RESULTS AND CONCLUSIONS

The results of our vehicle optimization case study showed our best design, after 77 simulation runs, had a reduction of 270 welds (3.8%) while not violating our set constraints. This design is reported in the Optim Welds interface, but there are other statistical tools within LS-Opt that may be used to examine the optimization results. Through the scatter plot, designs can be compared against each other to better visualize their relative performance.

The promising results of this vehicle crash case study demonstrates the robustness of Optim Welds and its capability of effectively reducing welds in an assembly.

	Number of Welds	Front Intrusion (mm)	Side Intrusion (mm)
Baseline	7094	64.7	195.7
Optimized	6824	60.5	185.3

Table 1 – Baseline vs. optimized design welds and intrusion

To conclude, Optim Welds is a user-friendly and guided spotweld optimization tool used entirely through the ANSA interface. The intelligence of the tool allows the user to perform a multidisciplinary optimization while maintaining consistent weld placement over all included models.

Through the process of targeting critical welds that are important to performance, we can reduce the number of runs necessary to find an optimal design compared to an ordinary spotweld line optimization.

Additionally, Optim Welds is not limited to the uniform weld spacing of a typical spotweld line; it's capable of creating designs that instead have a non-uniform weld distribution, which equates to a more efficient placement of welds. This means that welds that are not important to the performance of the model can be removed, which in turn increases the speed of production by reducing bottlenecks and ultimately lowers the cost of manufacturing that assembly.

Using our study as an example, a reduction of 270 welds with 5000 cars produced a week means a saving in welding costs of 3.5 million dollars in one year.

\$/Weld	\$/Car	\$/Week	\$/Year
0.05	13.5	67,500	3,510,000

Table 2 – Example of cost savings for 270 welds reduction in vehicle

REFERENCES

- (1) ANSA version 18.0.0 – 19.1.0 User's Guide, BETA CAE Systems
- (2) LS-OPT User's Manual Version 5.2, December 2015