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Forming simulations with NURBS shells in LS-DYNA

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Micro Abstract
LSTC (Livermore Software Technology Corp.) has started to implement NURBS based finite elements into their widely used commercial simulation package LS-DYNA. This work will give a short overview about the general possibilities of isogeometric shells in LS-DYNA and focus on the recent advances for the analysis of Sheet Metal Forming Applications. A benchmark example from the Numisheet 2005 conference is analyzed and compared with the results achieved with state-of-the-art methods.

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Introduction

Within the scope of Isogeometric Analysis (IGA) various types of basis functions are investigated by the researchers. Amongst them, Non-Uniform Rational B-Splines (NURBS) represent the most widely used geometry description in Computer-Aided-Design (CAD) and is currently the best understood spline technology for the use of finite element analysis (FEA). Therefore LSTC has started to implement NURBS based finite elements into LS-DYNA.

1 Finite Element Analysis with NURBS surfaces in LS-DYNA

This section describes some fundamental features and possibilities using NURBS surfaces for FEA in LS-DYNA. Due to space requirements, an introduction to NURBS is skipped here and the interested reader is referred to the literature.

1.1 A NURBS-patch

Doing FEA with NURBS surfaces in LS-DYNA requires the definition of NURBS patches using the keyword `*ELEMENT_SHELL_NURBS_PATCH`. In here, the geometric surface (control points, knot-vectors, ...) as well as the associated part and section properies are defined.

1.2 Interpolation Elements

On top of the NURBS patches, LS-DYNA automatically creates bi-linear shell elements (*interpolation elements*), whose nodes (*interpolation nodes*) are placed on the real surface. The interpolation elements may be used to apply boundary conditions (i.e. contact) and for post-processing. Its resolution can be defined using the parameters NISR and NISS (see Figure 1).

It is important to notice, that the interpolation nodes are fully constrained to the underlying NURBS patch. For instance, contact forces are in fact first evaluated at the interpolation nodes, but then transferred to the primary degrees of freedom (DOF) at the control points. The actual analysis is exclusively performed using the NURBS elements and their correspondig DOFs. For post-processing, results at the integration points of the NURBS elements are mapped onto the interpolation elements, such that standard post-processing tools can be used.

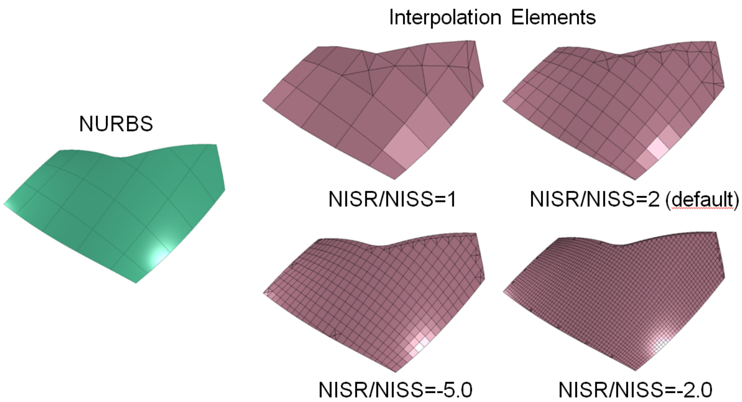

Figure 1. Bi-quadratic NURBS patch and interpolation elements dependent on the parameter NISR and NISS

1.3 Analysis capabilities

1.3.1 Shell formulations

Basically three different shell formulations are available. The first one is based on the Reissner-Mindlin shell theory and uses three translational and three rotational DOFs, similar to classical shell elements in LS-DYNA. As second choice a rotation free shell formulation based on the Kirchof-Love theory is available, that makes use of the higher continuity of the NURBS basis functions along the element boundaries. The third shell formulation is a mixture of both, leading to a hybrid formulation. It permits to individually define control points with or without rotational DOFs. As the continuity of the shape functions in a NURBS patch drops to C^0 at the patch boundaries, the hybrid shell formulation provides the possibility to couple regular NURBS patches along their patch boundaries by locally introducing rotational degrees of freedom while still exploiting the higher continuity in the interior of the patch.

1.3.2 Integration rules

Different integration rules can be defined using the parameter INT. A uniformly reduced (default) and a full Gauss integration scheme is available for all NURBS shells, irrespective of the order of their shape functions. For C^1-continuos bi-quadratic NURBS an additional, reduced patch-wise integration rule based on the work of Adam et al. [**?**] is implemented, which is characterized by the least amount of necessary integration points.

1.3.3 Trimmed NURBS

Based on the work of Nagy and Benson [**?**], the support of FEA on trimmed NURBS surfaces has been added to LS-DYNA. An unlimited number of trimming loops can be added to the general patch description to define the outer boundary of the desired surface and to cut out various holes in the interior. In Figure 2 a plate with a circular hole has been analyzed to compare the trimmed NURBS with respect to the standard well-established bi-linear shell elements. Both simulations give very similar results and given the fact that using trimmed NURBS allows the use of a regular spaced grid of control points, the displacement field can be represented a little smoother than with standard FEA.

1.3.4 Miscellaneous

Besides the already mentioned possibilities, the NURBS-based shells can be used in explicit as well as in implicit analysis. They are availabe in SMP (shared memory parallel) and MPP (massively parallel processing), a NURBS contact is implemented, boundary conditions can be either applied directly to the control points or to any location on the surface by constraining a massless node onto a NURBS patch. Many material models from the LS-DYNA material library

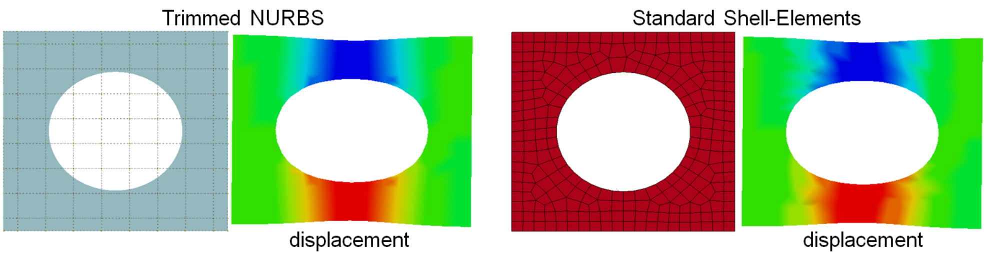

Figure 2. Plate with hole: Comparison of trimmed NURBS (left) vs. standard Shell-Elements (right)

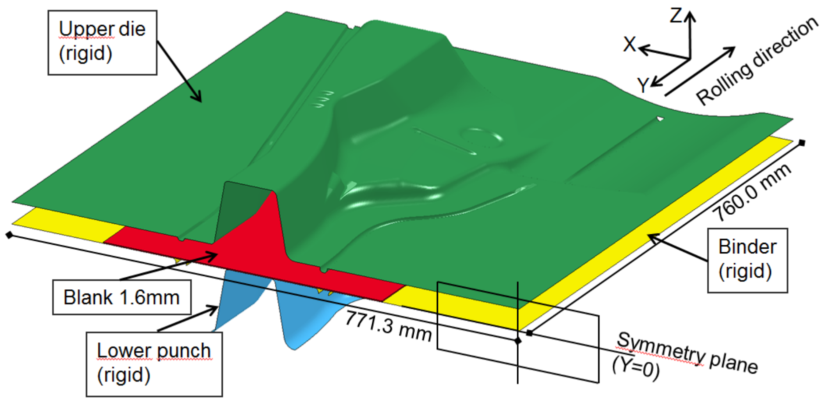

Figure 3. Numisheet 2005 - BM2 setup [?]

are available. Furthermore, regular mass scaling and rigid bodies are supported.

2 Example: Underbody Cross Member - then and now

The Numisheet 2005 Benchnmark on *"Forming of an Automotive Underbody Cross Member"* (BM2) [?], which was already analyzed by Hartmann et al. [?] in 2011 with one of the very first versions of IGA in LS-DYNA is reanalyzed and compared with respect to the first attempts.

2.1 Example setup

The setup of the forming process is shown in Figure 3. Only the deep drawing process is simulated, where the tools (upper die, binder and lower punch) are modelled with rigid elements. For all analyzed models, only the discretization of the blank was varied, while all remaining settings remained unaffected.

2.2 Results

The study by Hartmann et al. [?] has shown, that for qualitatively good results, an average mesh size of 2mm for the blank is needed when using standard, fully integrated bi-linear shell elements (ELFORM=16) and an average mesh size of 4mm when using bi-quadratic NURBS elements. Therefore the example has been re-computed with these two element formulations and their necessary level of discretization. In Figure 4 the equivalent plastic strain distribution at the end of the forming step is shown. Both element formulations lead to very similar results, which is also true for other important forming results like thinning.

2.3 Numerical performance

In the study from 2011 [?], the analysis could only be done using a SMP version of LS-DYNA, without having the possibility of computing the thickness change nor using mass scaling.

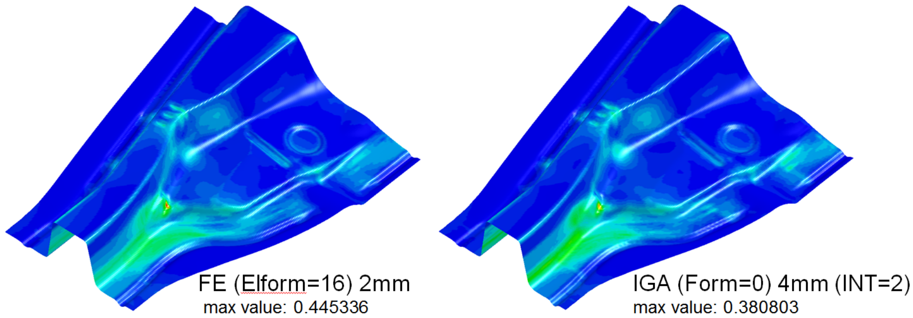

Figure 4. Comparison of equivalent plastic strain - standard FE (left) and NURBS (right)

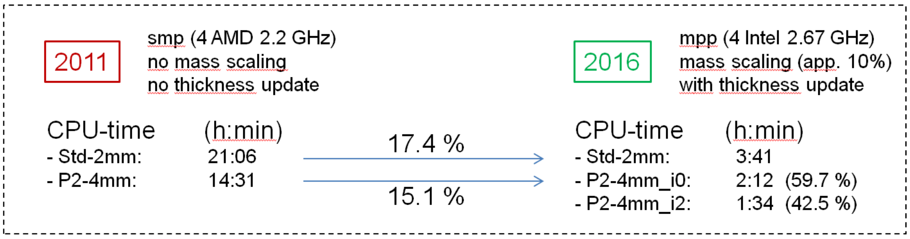

Figure 5. Comparison of computing time: 2011 [**?**] vs. 2016

Figure 5 shows the comparison of the computing time. It reduces significantly and in the same range for both element formulations. A further computing time reduction can be achieved by switching from uniformly reduced integration (P2-4mm_i0, INT=0) to the patch-wise reduced integration scheme (P2-4mm_i2, INT=2). In this example, the analysis with bi-quadratic NURBS shells (4mm) needs less than 60% than that with standard shell elements (2mm). Although the computational cost per NURBS element is significantly higher than per standard element, the larger mesh size, leading to less elements and a larger timestep size can easily compensate this extra effort.

Conclusions

NURBS shells in LS-DYNA and their performance in a forming example have been presented. The comparsion of the results with well-established bi-linear standard shell elements has shown, that the same qualitiy of results can be achieved with larger mesh sizes for bi-quadratic NURBS shells, which finally leads to a reduction of the computational cost.

References

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