Improvements in springback calculation and die compensation taking into account buckling, bottoming and shape control

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Abstract. In the recent years, springback calculation and the compensation of the tool shape has become standard practice. This allows shorter prototyping times and lowers the risk for bad die design. However, in some cases the results from simulation have not been as expected, leading to problems and delays as the reason is not always clear.

Reasons for this might be found in the phenomenon of buckling or twisting during the springback. This mode(s) can have a significant effect on the total springback. Therefore an additional buckling analysis during springback can help to improve the overall result of the springback simulation.

Another possible reason for deviations between simulation and reality might be the bottoming effect. At the very end of the process, the amount of press force applied to the blank can have a very big influence on the amount of springback.

This paper looks into the problem of instability during the springback and the bottoming effect. The aim is to improve the overall quality of the die compensation. Also in this paper we look into how to improve the surface quality of successful die compensation by introducing "shape control" – allowing the management of shape control during compensation, particularly important for external panels with design constraints

Key words: springback, compensation, buckling, bottoming, shape control.

1. INTRODUCTION

As shown in [Ling *et al.*, 2007], Forming simulation technologies continues to develop at a rapid pace, to address formability, tolerance control, and product performance issues in an increasing range of processes, and in ever more detail. Whilst forming simulation in the beginning was only focused on formability, it has moved, and is now focused around more advanced areas, such as springback and die compensation, surface quality and robustness.

This shift in focus has also meant new challenges towards the simulation systems. For the formability, strain based formability predictions have delivered good results in most cases. Springback being an essentially stress based phenomena however required for more advanced modelling techniques. The prediction of accurate stresses is far more sensitive than the prediction of accurate strain. Whist strain based formability assessments have been at an acceptable industrial level; this has not always been the case for springback predictions.

[Ling et al., 2007] suggest that there are a number of different parameters, some physical, and some purely numerical that are responsible for the sensitivity to the stress prediction. Parameters such as for numerical improvements using enhanced contact algorithms to ensure accurate respect of the discretized geometry, enhanced finite elements to simulate bending in a very accurate and robust way and sophisticated material models with elasto-plastic springback were discussed. Especially a lot of new materials introduces (Dual phase, TRIP, TWIP etc) made the need for more accurate material models obvious. Parameters for the process such as incorporation of geometric drawbeads as opposed to the more common equivalent drawbead models and closer integration between simulation and geometry were show.

By improving a number of these parameters, they could show that the accuracy of springback calculation and compensation could be improved significantly. But still, there remained some cases, where the simulation results could not be improved. Of course there might still be a number of reasons for this. In this paper we will look into 3 different methodologies proposed to further improve the quality of the springback calculation and the compensation thereof.

2. BUCKLING

Even though springback calculation has become common practice, in some cases it has failed, see *Figure 1*. In this case, the solver diverges and still has not found a solution after 337 increments.

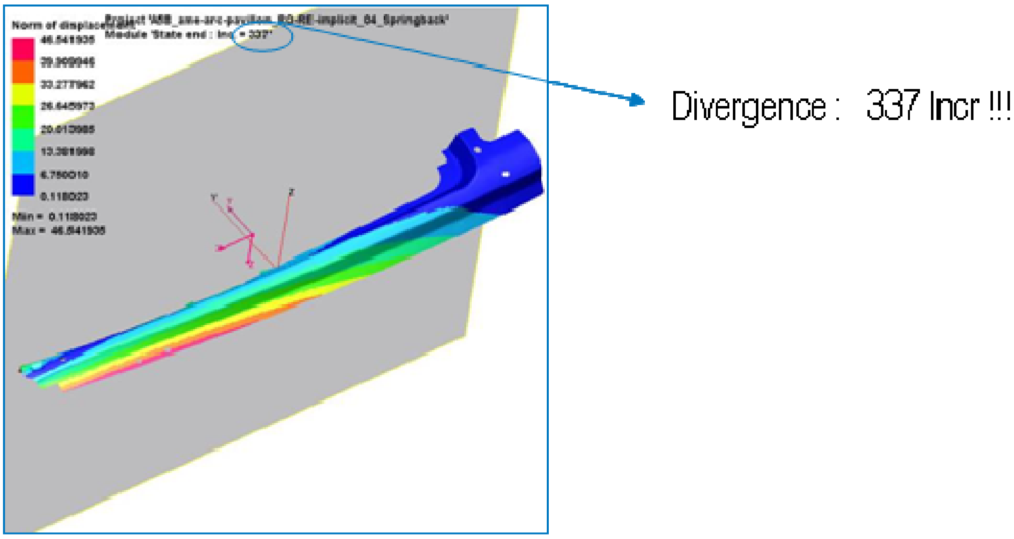

Figure 1: Sample where the traditional springback calculation fails.

The reason for the failure in this case is buckling. An Eigen value analysis (*Figure 2*) of the part shows that the part buckles just after the release from the tools, and solver does not manage to find a stable final position. One reason for the divergence is the fact that numerically, the whole part is released in one single moment. This so called brutal unloading leads to numerical instability.

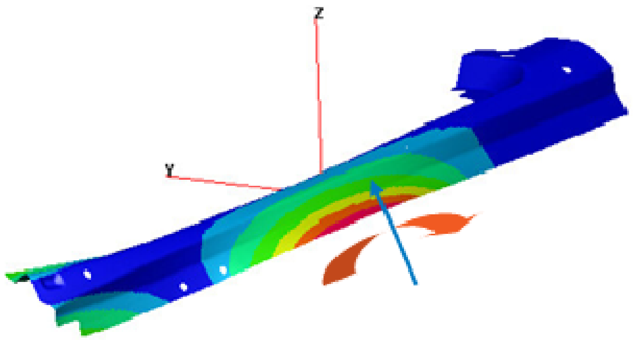

Figure 2: Eigenvalue analysis of the part

Looking into what happens in the solver, when there is a non-linear response, once we reach the limit point, the Standard Newton-Raphson method reaches its limits, see *Figure 3*. This can lead to divergence of iterative method, plasticity, contact, etc.

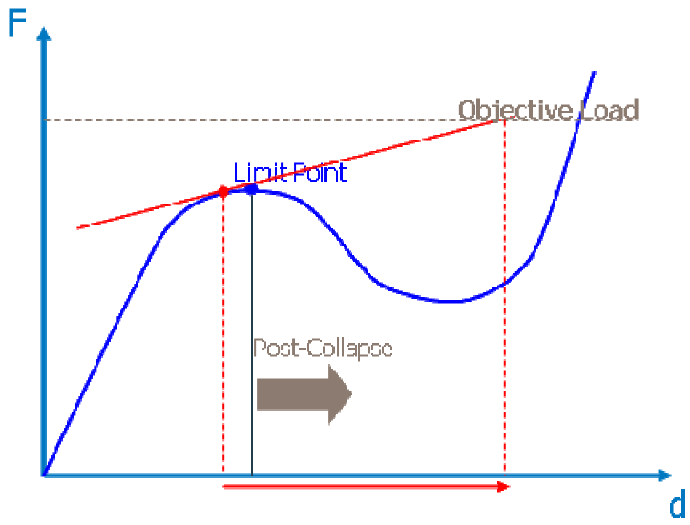

Figure 3: Post collapse analysis after limit point.

One possible improvement is to use the Arc-length method instead of the Newton-Raphson method in cases where these instabilities occur. Here the load increment becomes a variable, see *Figure 4*.

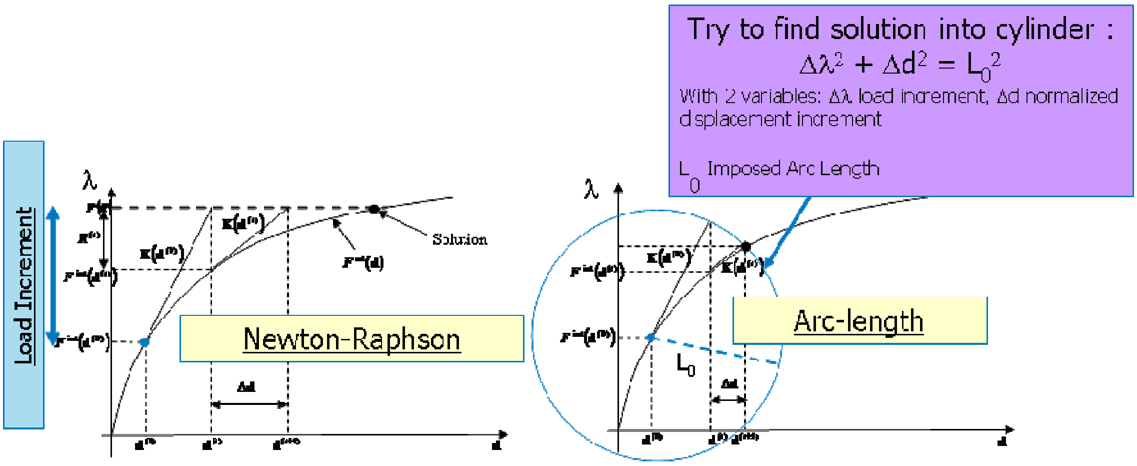

Figure 4: Comparison of the Newton-Raphson method with the Arc-length method.

The Arc-length method is efficient when instability affects global load-displacement response. If instability is localized and has no impact onto global response, Arc-length is not efficient. In these cases, we have introduced also a stabilizer by artificial volumetric damping, where a viscous Force is added to the Resdiu;
Residu = $F_{ext} - F_{int} - F_{visc}$

A combination of the use of the Arc-length method and stabilizer will then depending on the instability found lead to a convergence and a found solution for the solver.

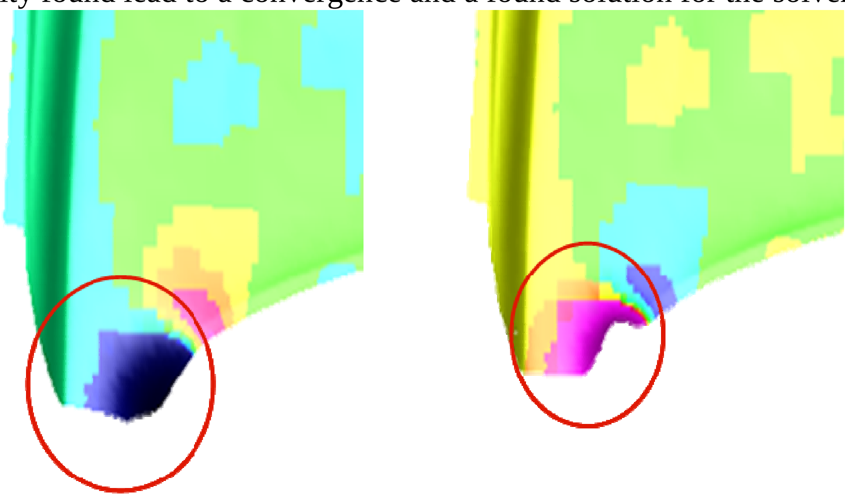

Figure 5: Using the new implemented methods for buckling analysis can in certain cases have a significant effect on the springback.

3. BOTTOMING

If the stamping process is followed by a bottoming effect, the high normal contact pressure which results from this, can have a (significant) influence on the springback. Not in all cases this will have an effect, but in some cases where the punch movement is past leaving the final gap equal to the blank thickness, where intendidly the punch force is high, combined with big flat areas, the influence from the normal stress will be noticable, see *Figure 6*.

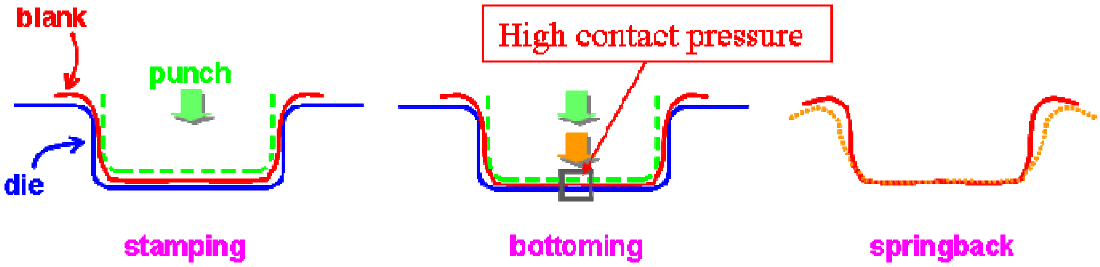

Figure 6: If the stamping process is followed by a bottoming effect, this can have a (significant) influence on the springback

A new “normal stress” shell, called Q5 for Quadrangles and T4 for triangles, has been introduced for better understanding and capturing of this phenomena. This shell element enables the calculation of the normal stress by adding one new virtual node at the centre of the shell with the needed degrees of freedom, to simulate the element compression, see *Figure 7*.

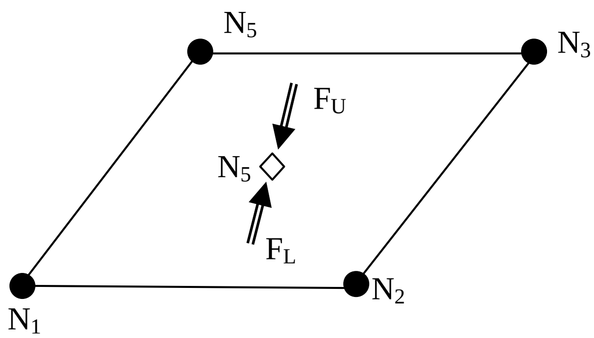

Figure 7: New normal stress shell element with one additional virtual node.

The upper and lower contact forces are transmitted to the shell virtual node. The virtual node degrees of freedoms dynamic equilibrium is solved by the calculation of the corresponding normal accelerations, velocities and displacements. Then the full 3D plasticity equations are solved, giving us the 3D normal stresses. A simple test shows already the changed behaviour and amount of the springback, see *Figure 8*.

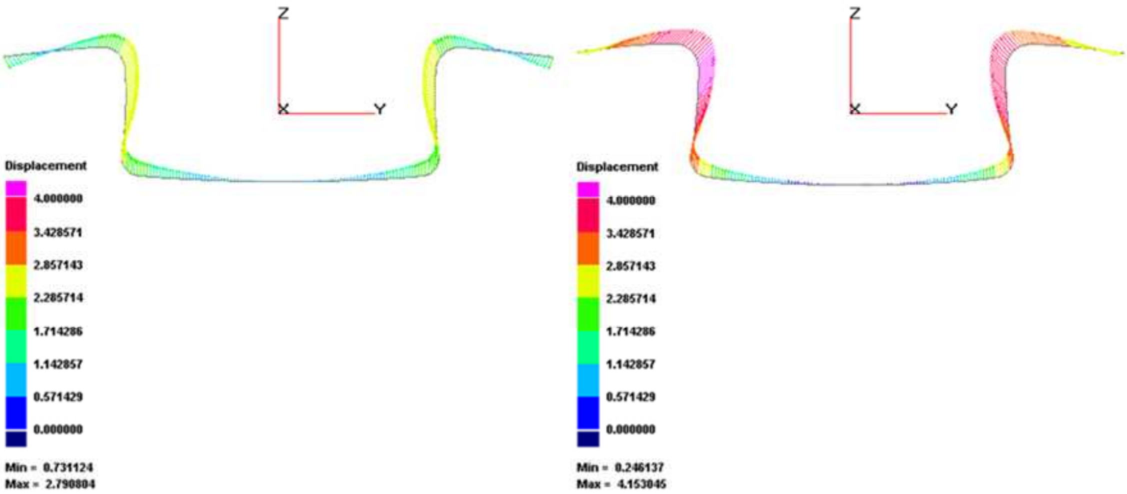

Figure 8: Test of the new normal stress shell element (left) compared to the normal shell element (right) – amount of springback

Then a test was done with a box case, where after the stamping the punch pressure was increased until a 10-20% thickness reduction in the bottom was achieved, see *Figure 9*.

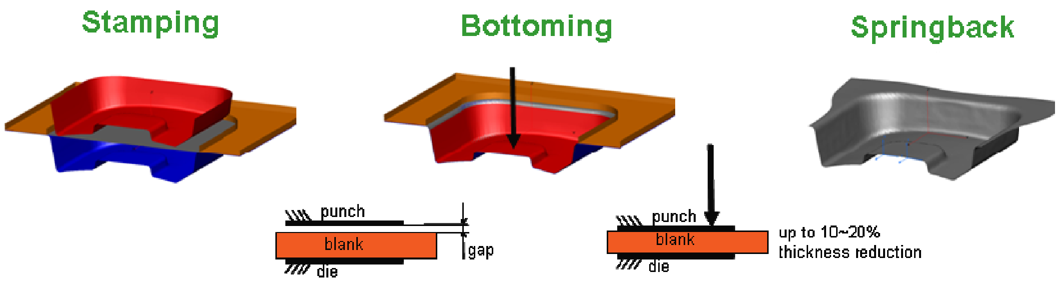

Figure 9: sample case for calculation of the bottoming effect on the springback.

The results from this test are shown in Figure 10. As it can be seen from these images, the amount and direction of the springback changes completely.

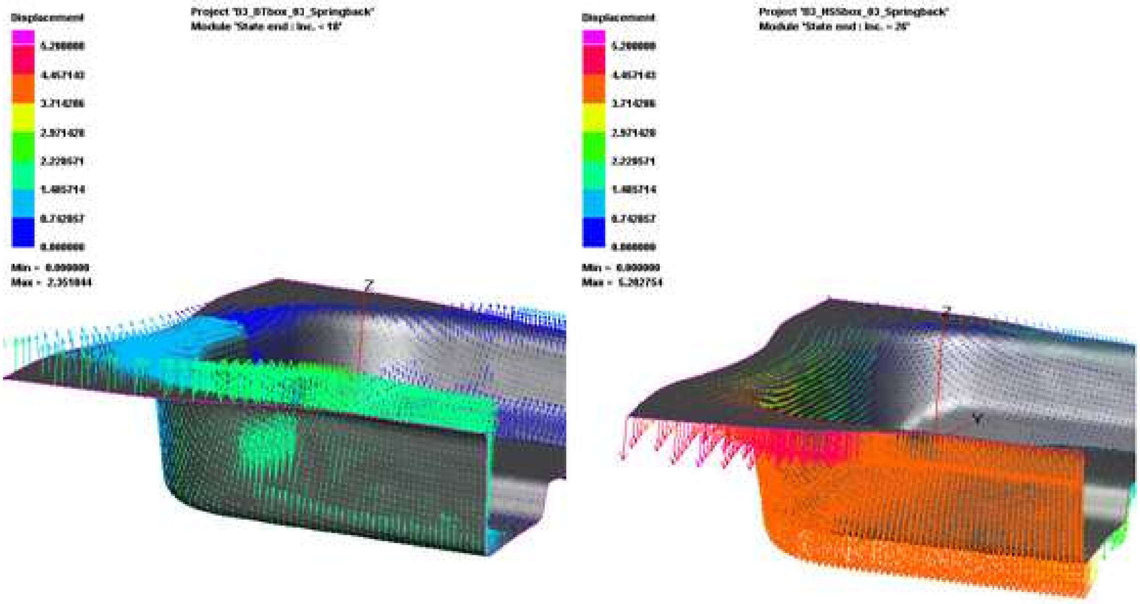

Figure 10: result of the calculation of the test case. Left side, the traditional shell element, right side the new normals stress shell.

4. SURFACE QUALITY AFTER DIE COMPENSATION

Even if the springback calculation and the following die compensation has been successful – within given tolerances in distance between part after springback and objective, it's not sure the final result of the compensated geometry satisfies the requirements towards surface quality. Small waves, bumbs or hollows might be the result. This might occur even if different smoothing algorithms are applied during the CAD reconstruction phase – see samples in *Figure 11*. This means that already during the springback & compensation stage, the surface quality has to be controlled.

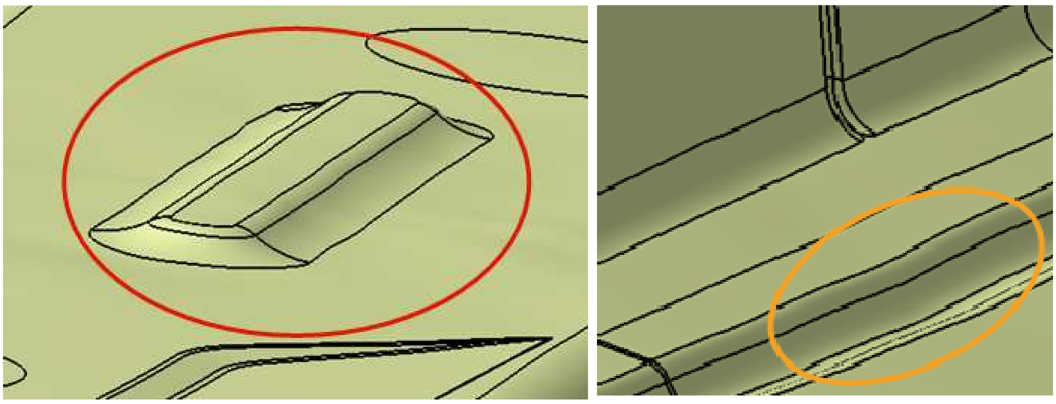

Figure 11: Samples of reconstructed surfaces where waves or bumps disturb the surface quality.

Several functionalities enable to control the shape during die compensation and thus the final quality of the surface:

- Part of the die can be locked so that the compensation does not modify it. This could be very important for some design shape or style lines.
- Other area of the tools can be managed by sample techniques that control the imposed displacement field during the compensation and prevent the “waves” effect

Swich on is best to use depends on the part, geometry etc. But using these options, can significantly reduce the bumbs and waves, and is normally better than the reference used here – the smoothing functions from CAD systems, see improved samples in *Figure 12*.

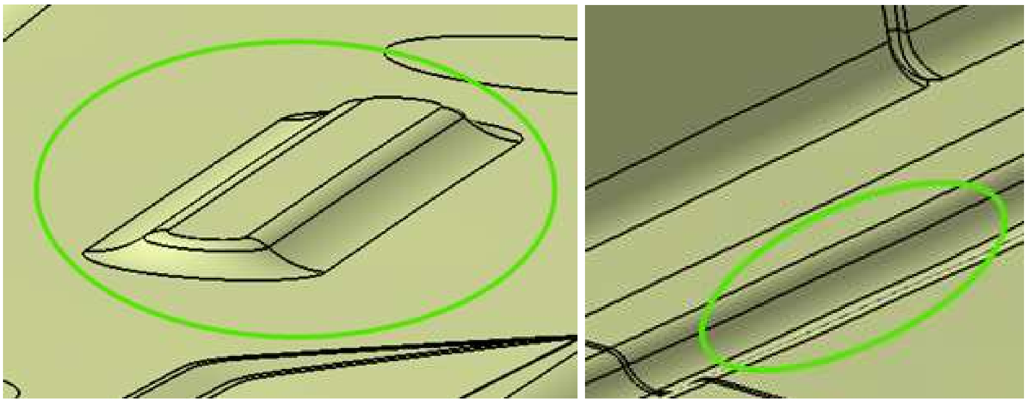

Figure 12: Significantly improved surface quality after introduction of shape control during the springback compensation.

5. CONCLUSION AND OUTLOOK

In the past, sheet metal forming simulation has moved from being simple formability assessment tools, to become more advanced tools for virtual manufacturing. Calculating springback accurate and compensate it is part of the virtual manufacturing chain. Springback however is a complex phenomenon that sometimes requires more attention than the forming process itself. In the past different measurements have been performed to increase the accuracy – such as improved contact algorithms, material models etc. In this paper, 3 more ways to improve the springback quality have been presented, taking into account the bucking and the bottoming effects and the shape control. For certain cases, one or more of these methods will allow the user to improve his results for the springback and compensation. If previous and now added methodologies are enough to solve all the different phenomena that can occur is not sure. More testing is needed to find that out.

But the demands on the industry to move towards full end to end virtual prototyping means that the virtual manufacturing part has to work streamlined. For the sheet metal forming process this means that all stamping, flanging and hemming operations have to be calculated accurate enough to allow decisions to be made based on these results. This also includes springback and die compensation.

REFERENCES

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