Engineering and Stiffness-Weight-Optimisation of the Main Innovative Part of the Portalharvester - The Linking Bridge - Using FEM

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Abstract:
The new invention of the Portalharvester was introduced at FORMEC in 2008. The special machine for sensitive forest soils moves in a new, patented manner, by which it will be possible to impact just four per thousand of forest soil. Basic and most innovative part is a segmentable and boltable bridge, that realises step width of 4, 6 or 8 m and that is 10 m long at all. On top of it a harvester cabin (six and a half tons) with a standard harvester crane (10 m outreach) and head (felling diameter up to 45 cm) will be able to slide along and deal with 500 m² of forest stands without any relative motions in terms of the soil and slip. While several critical phases can occur like working in the middle of the bridge or swinging out the bridge at moving, the structure has to be forcefully optimised in relation of multiaxial stiffness and weight. Strain has to be used for minishing stresses alongside the structure.
FEM is used for several propositions. First to choose a type of light-weight design, that seems to be perfect for optimisation and the general dimensioning. After designing solutions for multi-dimensional segmenting, bolting, bearing, driving, transmission of energy, actuating and energy space management, the structure again is finally optimised with FEM. In that way, all boundary conditions have to be fulfilled, the locations of maximum/minimum stresses have to be boost/minished or rearranged. Other than conventional harvesters, that need a high weight to avoid overturning, for the first time the chassis of this forest machine needs aspects of light weight engineering. The chassis will be imaginable for a lot of alternative applications. A real working forest prototype of a Portalharvester actually is built in Germany.

Keywords: harvester, engineering, light weight construction, FEM, sensitive forest soils

1 Introduction

Today´s forest technology is less suitable for harvesting on sensitive sites or wet forest stands. Wheeled or crawler-based harvesting machines, i.e. most of all forwarders, seem to touch at their technical, economic and above all environmentally acceptable limits. The interaction of machines large dead weights, unavoidable slip and frequent crossings causes long lasting and extensive soil damages. Although, forest technology has to mediate in the public conflict field, on which an extremely sensitivity to environmental destruction and soil protection by law meet an economical demands that are determined by year-round profitable timber harvesting.

In recent years science and industry attempted with numerous innovations to satisfy the demands of society, ecology and economics (Wehner et al. 2010, Jönnson 2012, Loboda 2009, Loboda 2012, Weise 2003, Kubatta-Große 2010). But today, forest harvesting on wet sites in Central Europe cannot even satisfy two groups simultaneously. Either used harvesting methods are careful, but at the same time too expensive and unproductive (Becker 2009). Or they are cost-effective but the machines leave serious soil damages or will sink in the mud indirectly. Without any alternative, users can choose between the acceptance of large-scale, long lasting damages to the forest soil and the loose of passability of skid lines or at a more expensive choice, the costs of the careful harvesting method possibly will override the timbersale. Without subsidies in many places, such in the German district of the Spreewald, the forest management like thinning or harvesting will remain undone. In times of increasing energy shortage of fossil fuels, the waiver of utilization of large forest areas with sensitive forest soils, which inforced the impact to less sensitive and richer ecosystems by today's forestry technology cannot be tolerated.

But the symptom is not limited to more or less rare wet forest stands. The crossing of huge machines on humid forest soils isn´t a niche and does not limit itself to flat forest sites. Depending on weather situation, slope and type of soil, the risk of enormous soil damages appears all around Europe: in Portugal as like as in Scotland, in Estonia, Finland or in Slovenia. Especially in the moist winter months and during the snow melting period, the proportion of sensitive areas of the German forest sites rise to up to one-third of the total forest area. The creation of a permanent skid road network, which already holds about 20 % of productive forest area, during this period cannot longer guarantee its passability.

One solution of an ecologically sustainable and economically compatible forest machine for harvesting of short wood on wet sites is the so-called "Portalharvester" (Knobloch 2008). It moves alongside a foldable bridge, which is mounted on two tripods. Upon this bridge a carriage is mounted that acts like a conventional harvester and can move from one side of the bridge to the other. If it is located on top of one tripod the bridge can be lifted up and moved around, so it will be possible to position the bridge and the second tripod in a distance of 4, 6 or 8 meters without any limitations. In doing so, only 4 per mill of the forest area are touched by the moving machine. While working, the Portalharvester is resting on both tripods, and the harvester head will be able to reach more than 500 m^2 of forest area. The new solution of movement allows for a great adaptability and soil preservation. Without occurrence of slip and elongated, continuous and linear soil compaction, the principle of movement of the Portalharvester realises a stepwise positioning on wet or baffled (rock-overlay, ditches) terrain. Huge bounding surfaces allow a quick regeneration of the small impacted areas. In that way, the Portalharvester doesn´t need any conventional skid trails for harvesting or thinning at all.

A cable way system with some innovative features will be responsible for the transportation of the short wood logs towards to the forest road. Both machines will be working together in several new designed processes.

1.1 The study's problem area

The Portalharvester combines a low dead weight with high power density. The performance and stability of a Portalharvester importantly depends on the optimal condition of its innovative core component, the bridge that connects the two tripods. The bridge should be of light weight in order to maximize the step size and the stability against overturning. On the other hand, it needs to be solid and resistant enough to allow functionality in any position and all harvester crane positions. In addition, it has to fulfil a lot of boundary conditions. It has to be foldable and in that way to be bolt for realising a minimised turning radius and a minimum transport volume. In addition the carriage needs to move on the segments and the needed energy (electrical, hydraulic) has to be conducted alongside. In general, the bridge should cope with harsh forest conditions. While manufacturing, the bridge has to remain easy producible and cost-effective. Especially the call for light weight seems to be a hidden call for cost driving. Therefore, the forest machinery manufacturing principle as a conventional steel welded construction is to be retained, albeit high-performance steels with much higher yield strength than conventional steels will be used.

The core task of the engineer focuses on the optimal balance between low weight and maximised load capacity of the bridge. Other than conventional harvesters, that need a high mass to avoid overturning, for the first time the chassis of a forest machine needs aspects of light weight engineering.

2 Material and methods, area of interest

With help of the FEM-tool of the middle class standard CAD software "SolidWorks" in version of "2012 Professional", the bridge design and engineering is optimised at various states of work (see figure 1). In the process, the particular CAD model is divided into finite elements and calculated using the finite element method (FEM), an iterative simulation of solid-bodies (Mayr and Thalhofer 1993, Bathe 2002). This approximation to the exact solution of the differential equation (real deformations, stresses, reactions) is only a blurred image of the real solution. In doing so the simulation is approximated in a second iteration using the h- and p-method. Thereby the quality of the finite element mesh will be improved as long as to the solution (occurring the von-Mises-comparison stress; displacement) will come up to a stopping criterion (1 kN/mm^2; 1 mm). In that way, the simulation is sufficiently close to reality. In a third iteration, the results with an acceptable accuracy are evaluated and chosen out of several optimised variations to modify the engineering. The process stops, if the changes between two iteration passes are small enough. The assessment of the marginality in the third iteration is purely subjective and is depending on the variety of boundary conditions.

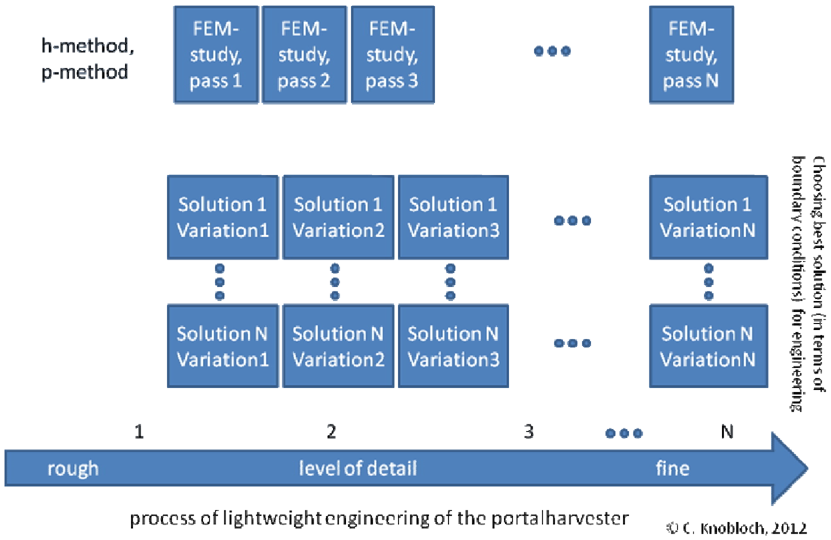

Figure 1: Process of lightweight engineering of the Portalharvester

The improvement of accuracy is achieved at the h-method by a local increment of the number of finite elements, at the p-method by increasing the polynomial degree in the respective element. Depending on the object and level of detail, the h- or the p-method work in a better way. Following up states of work are examined in regard to minimum weight, maximum stiffness and sufficient elasticity to absorb and transfer tension in an optimal way.

2.1 Determination of type of engineering

Out of three applicable design principles, the best type of engineering has to be determined. For that, with help of the h-method, the results of several FEM-simulations are compared. Thereby the kind and location of the load input and bearing are equal to the different test designs. The h-method helps to offset the influence of an error at low polynomial order (for example to rounds or bevels). All variants were analyzed under the same load (simultaneous transverse bending and torsion). Examined are following design principles:

⇒ framework design (girder mast),
⇒ fully enclosed profile design (airplane wing),
⇒ quasi-framework design in opened profile design (excerpts from the full-profile approaches to the framework design).

2.2 Determination of the cross section

The second step is to determine the optimal cross section. That covers the preliminary fixing of total height, total width, the plate thickness, the placement of mould parting lines and the angles of bending in consideration of the initial forces from the upper carriage, susceptibility to dirt and moisture deposition zones or manufacturability. The area moment of inertia against bending and torsion has to be maximized, the mass per linear meter has to be minimised. The extruded profile up to 1 meter is analysed again in several solid-state simulations using the p-method. The stress and deformation responses of the composite load is optimised iteratively with FEM.

2.3 Determination of the basic structure

As soon as the optimal basic structure is found, the design phase is completed and the engineering phase starts with the holistical elaboration of all details. In regard to the segmentation, the needful bolting and the indispensable disruption of force lines, by using of FEM and the h- and the p-method, the dimensions and especially the geometric layout of perforated stiffening elements has to be determined. This stiffening elements are for example stringers, ribs, bulkheads or frames. Load und bearing has to be in the simulation similar to reality.

The simulation, in which the engineered design is loaded quasi-dynamically and composed under worst case conditions (torque of 100 kNm and shear force of 100 kN) causes a superimposed deformation out of torsion and bending. An elasticity is desired to a certain extent, because it helps to reduce stress peaks. On the other hand increased elasticity probably will lead to malfunction of the carriage.

2.4 Detailed engineering

Based on the third step, the detailed engineering can start. Now the whole engineering is analysed in general and in important details. Thereby it is the task to increase the safety factor while minimising stress peaks and establishing a uniform overall strain.

While using the extensive multi-body simulation for optimisation, other load cases, for example the expanding and retracting of the bridge is quasi-dynamically analysed, too. For example in cases with low strain, but different locations of stress peaks, the moments and force lines are examined. That helps to check out the flaws as sites of fracture or on the other hand to find zero stress points, which open doors for undersizing in order to save weight as long as the production cost would not negatively be affected. At all, FEM helps to find a lot of small critical stress areas, too.

3 Results

3.1 Determination of type of engineering

In consideration of occurring deformations, equivalent stresses and the dead weights, a direct comparison of the three, separately optimised designs turned out that the framework design (a) shows comparative huge stress peaks (up to 1.200 N/mm^2), resulting from the torsional load at the nodes. Because of that, the design is inevitably greatly oversized and shows a high dead weight of 147% compared to the preferred alternative design. The perforation of the Quasi-Framework design (c) contributes less to the weight reduction, but increases stress concentrations in a negative way. The comparatively ideal solution seems to be the fully enclosed profile design (b), wherein the applied torsional loading, resulting out of the eccentric harvester crane, could conducted along helical stress lines. The closed field of sheet metal, as a static element of the plate, arranged as an edged and closed design, is ideal to fulfil beneficial properties in a thin and slightly way. Two in the neutral fibre connected, full-edged plates with internal, perforated web plates resist the transverse bending, resulting from the dead weight of the upper carriage.

Table 1: Results of the determination of the type of engineering

Design	Deflection in mm	Mass in kg	max. von-Mises comparison stress in N/mm^2
a	110	916	1.212
b	65	623	568
c	69	612	487

3.2 Determination of the cross section

The dimensioning of the metal skin in width, height and thickness including the internal web plates is the result of the optimised cross-section calculation via FEM. Numerous web-plate-variants are examined. While making the deflection constant, with that step of optimisation about 35 kg (just the supporting structure) are possible to save.

3.3 Determination of the basic structure

By means of FEM, it is possible to add and remove material at several critical points selectively. In that way, the weight could be reduced and deflection is set within a tolerance range that minimizes torsion and stress peaks, but keeps elasticity. Moreover, an optimal flux of forces an moments will be guaranteed (see figure 2 that shows all areas which stresses are more than 100 N/mm^2). While freezing the preliminary design, the geometric design of the segmented carrying structure including the internal stiffening plates is fixed. Because of its high stability and lightweights thin metal box construction the result looks like an airplane wing. The deflection can be reduced by the added stiffness from 62 mm to 53 mm, the weight of the refining carrying structure is about 1.240 kg. The normal stress alongside the structure is about 400 N/mm^2. While using a high-tech-steel with yield strength about 700 N/mm^2 and a coefficient of safety of 1.5, maximum stresses of 460 N/mm^2 are allowed. But due to the lack of sharp edges, corners and bevels in the CAD model in this state of work, the basic structure shows minimal-sized stress peaks about 1.200 N/mm^2.

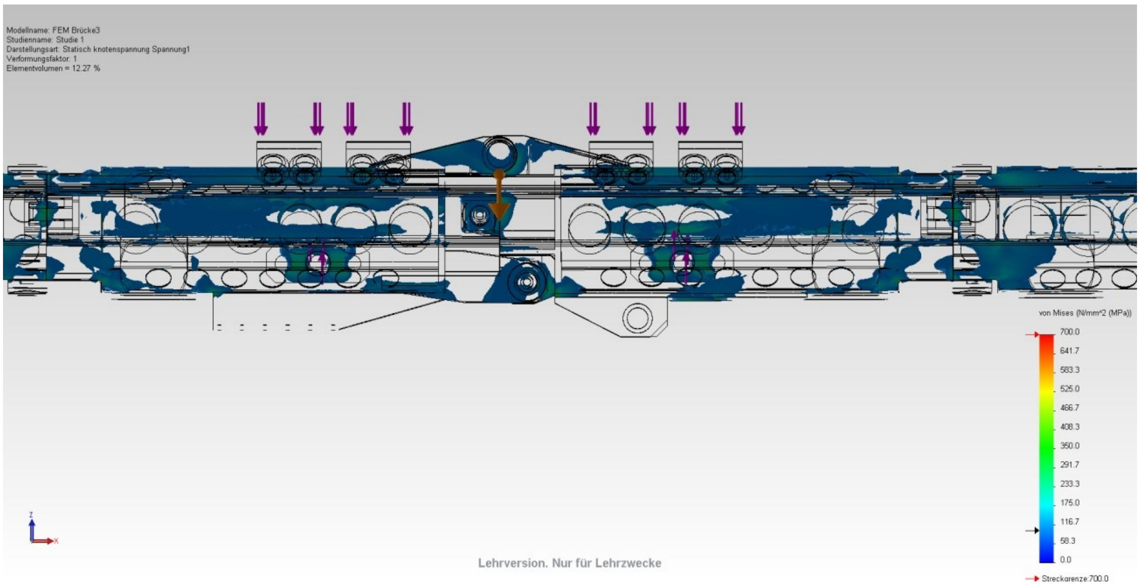

Figure 2: Detail of the bridge, in that all stresses are shown, that are more than 100 N/mm^2, an optimal flux of forces is established

3.4 Detailed engineering

The assessment of the detailed engineering shows that the deflection is possible to reduced down to 16 mm, although the total weight including all bearings, hydraulic elements, rails etc. rise up to 2.400 kg (see fig. 3). That doesn´t sound too light, but if ones take into account, that the 10 m long bridge has to cope with enormous loads and at the same time has to meet boundary conditions like segmentation and bolting, passability of the 6 tons upper carriage on rails, portability etc., the weight of the bridge is quiet low. As relation it has to be stressed out, that a normal harvester crane has about the same weight like the whole bridge. A typical iteration after the p-method is indicated in figure 4.

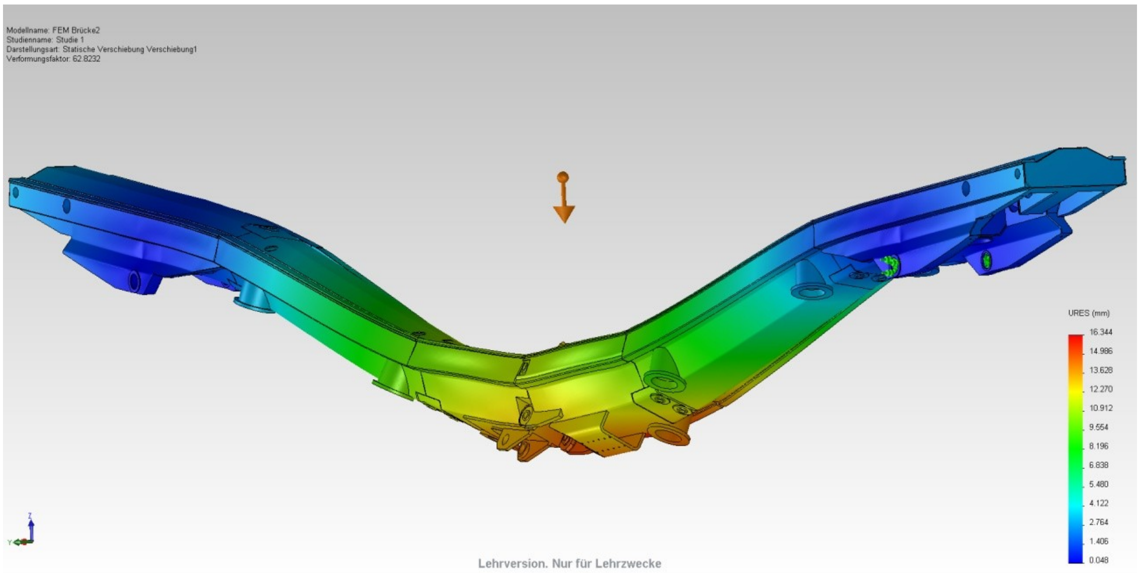

Figure 3: Illustration of the 62-fold increased deflection of the bridge, that is visualising the elastic behaviour of the bridge (flexible or rigid parts are possible to identify)

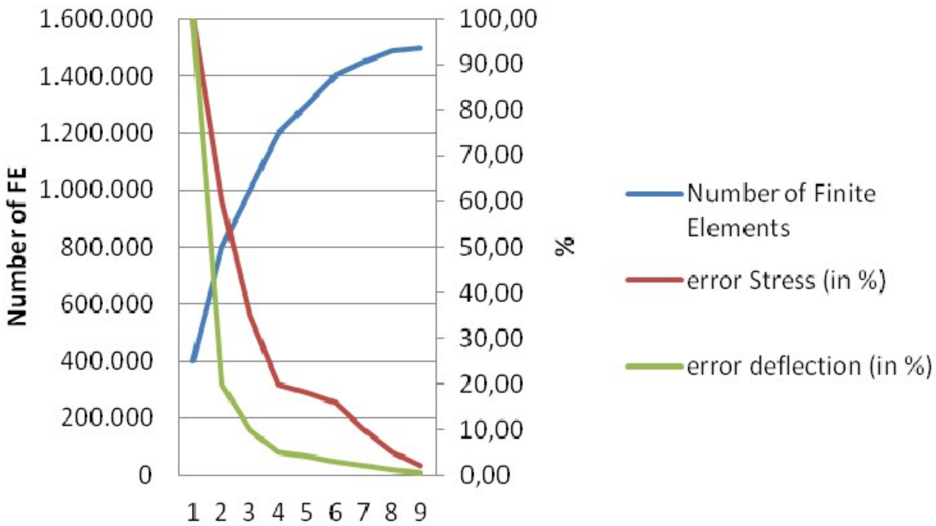

Figure 4: A typical iteration after the p-method; the iterations stops after fulfilling an abort criterion at pass number 9

4 Discussion

Scientific engineering, if not in field of the basic research, is an applied science and tends towards to be rather empirical, in which subjectivity and creativity of the engineer has a great influence. Each problem and each sub problem of designing and engineering process is always new and needs constantly recent solutions. Just the engineering methodology is similar. In a holistic proceeding of constant detailing the finite elements method is a useful tool, with that optimisation could start from an early work stage on.

Further, unpredictable influence-impact-reactions can be detected easily. However, the numerical procedure involves risks, because the approximate solution is only little quantitative information in relation of reality. With the help of the h- and p-method, the assessment of the impact of errors is possible. However, a finite element model simulation should be used for qualitative orientation only.

Whether the model is coarse or fine, it cannot include all geometric (computing capacity) or any material scientific influences. Nevertheless, the FEM allows the detection of the main stress zones and those with potential material savings. A (scaled) deflection illustration shows the elastic behaviour of the carrying structure and highlights weaknesses and extreme deformation zones. The complex application of the FEM is in consideration of possible numerical lacks a powerful tool to introduce lightweight aspects in structures of forest equipment.

5 Conclusion

The development of the bridge of the Portalharvester wants to show how to attend aspects of light weight structures in forest machines. Because of the novelty, the study has the lack of a quantitative comparison to the weight of a conventional solution. Nevertheless, the application and implementation of light weight aspects in several stages of engineering work are all-dominant for success or failure of the new invention. Without the FEM, the creation of an optimized light and stabile carrying structure would not have been possible.

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