FAST VISUALISATION OF SAFETY MARGINS OF THE W7-X PLASMA VESSEL

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ABSTRACT

For the case of structures containing a great number of elements, the postprocessing of commercial programs offer the interactive visualisation of different computer based results. Some special tools are missing so that the FE-engineer can get more advance to evaluate the results. Based on the analysis of the W7-X plasma vessel, different options are shown. Some of these are: The estimation of the influence of local peak stresses, the fast visualisation of extreme values for wireframe and hiddenline applications, the evaluation of different materials (yield limit) with respect to safety requests. Since each stress component has its own yield criterion, the evaluation of the safety margins has to be done with care.

Different illustrations of these options are shown. Since commercial programs do not offer these utilities, special codes had to be written for this purpose.

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Introduction

A new plasma fusion experiment WENDELSTEIN7-X (W7-X) is under construction at the Greifswald Branch Institute of IPP. With the aim to use the profit of energy by the deuterium - tritium fusion, some characteristics of the actual W7-X magnet are: 5 field periods each comprising 10 non-planar coils with a major radius of 5.5 m and an average coil radius of 1.25 m. The magnetic induction on the plasma axis will be 3 T with a current of 1.76 MA per coil in the standard case. Superconducting coils provide a steady-state field. The assembly of the non-planar coils with the additional planar coils is shown in figure 1. A point of interest is the plama vessel inside the non-planar coils which provides the enclosure for the ultrahigh vacuum of the fusion experiment.

The surface of the plasma vessel consists of regions with transitions from convex to concave domains. The question about the safety of the vessel refers not only to the global outside pressure of 1 bar, since additional forces are induced by the bellows of numerous diagnostic ports. Figure 2 illustrates the complete vessel with its ports and the bars which represent the bellow forces.

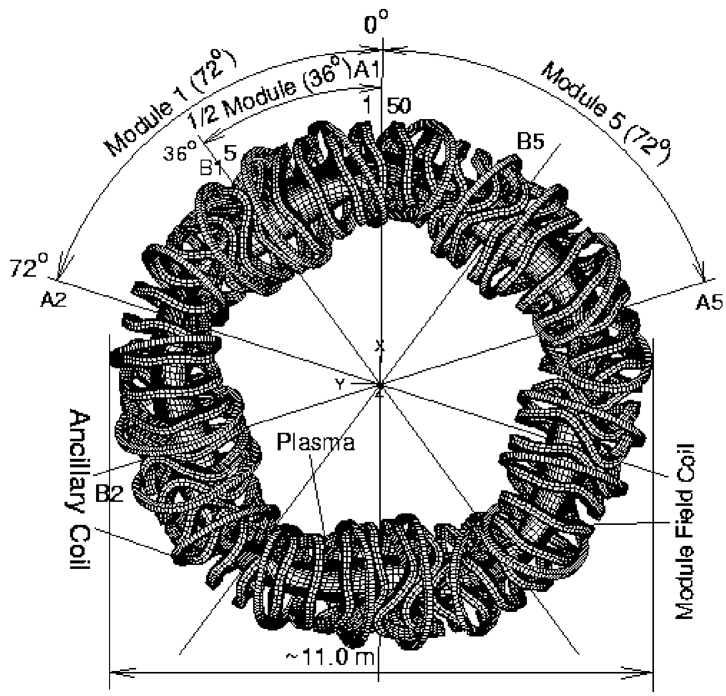


Figure 1. The W7-X magnet with 50 non-planar and 10 additional planar coils which are operating in the superconducting state [1].

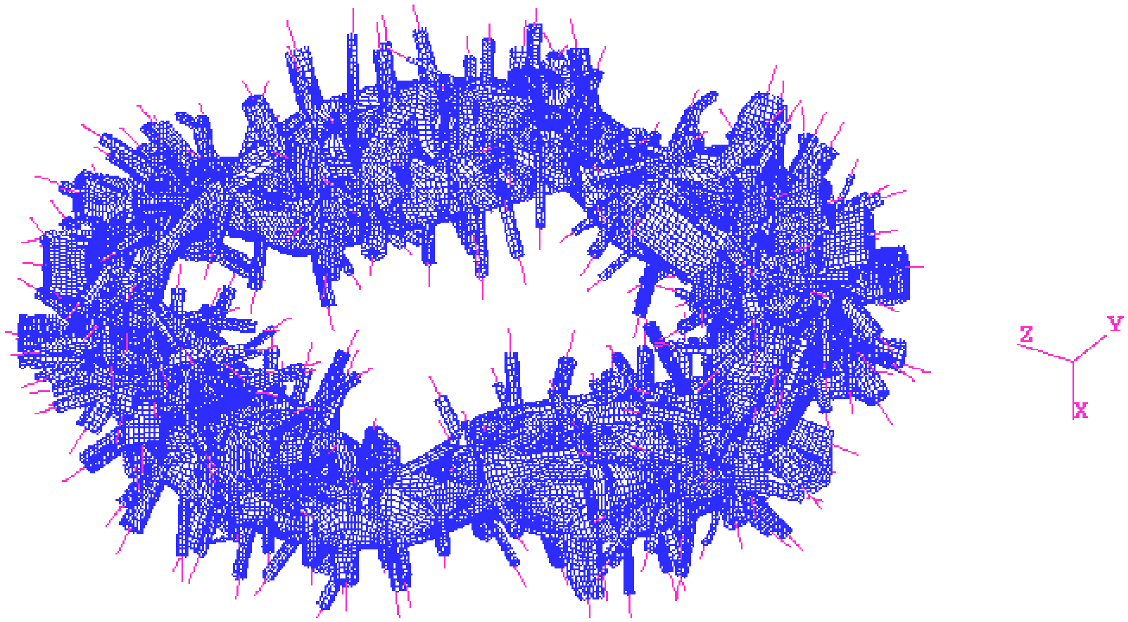


Figure 2 The plasma vessel reflects the 5 period assembly of the magn... merous diagnostic ports with bars simulate the bellow forces for the FE-calculation.

Assumed conditions to get FE-results of the W7-X plasma vessel

The geometry of the plasma vessel is constraint by two conditions: It has to be positioned inside the free space of the non-planar coils and the distance from the outside surface of the plasma should be large enough for a safe attachment of all the in-vessel components. The material of the wall is stainless steel, the global wall thickness is dimensioned by 17 mm.

Except the buckling analysis, the static calculation of the displacements and stresses has been performed on a 1-module section of the plasma vessel. This assumption is acceptable since most parts are similar at the other modules, there are some discrepancies at individual diagnostic ports only.

Different load cases have been considered to simulate different operating scenarios. The external pressure is 1 bar and is changed to the value of –1 bar to get results for the case of an internal load when the vacuum of the plasma vessel has a temporary leakage while the cryogenic vacuum within the outer vessel remains unchanged. The gravity constant is multiplied by 1.8 to get the realistic weight of the additional in-vessel components. Additionally, the influence of the temperature during the phase of heating up is computed introducing an uniform temperature of 150 ^{o}C.

The FE-model with the loads has been generated using MSC.Patran [2]. The results of some of these load cases are shown in different illustrations. Since the context to special functions is described together with the values of the FE-computations, preference is given to present the drawings at the following sections.

Tools for the fast visualisation of extreme values

The power and the computing speed of the workstations has been increased until today. The necessity to get a visualisation of the results as fast as possible called for different techniques for the postprocessing dependent on the number of actual elements or the speed of the graphic power. Three independent hiddenline routines have been developed for an interactive usage which will be chosen by the program automatically to guarantee an optimal performance [3].

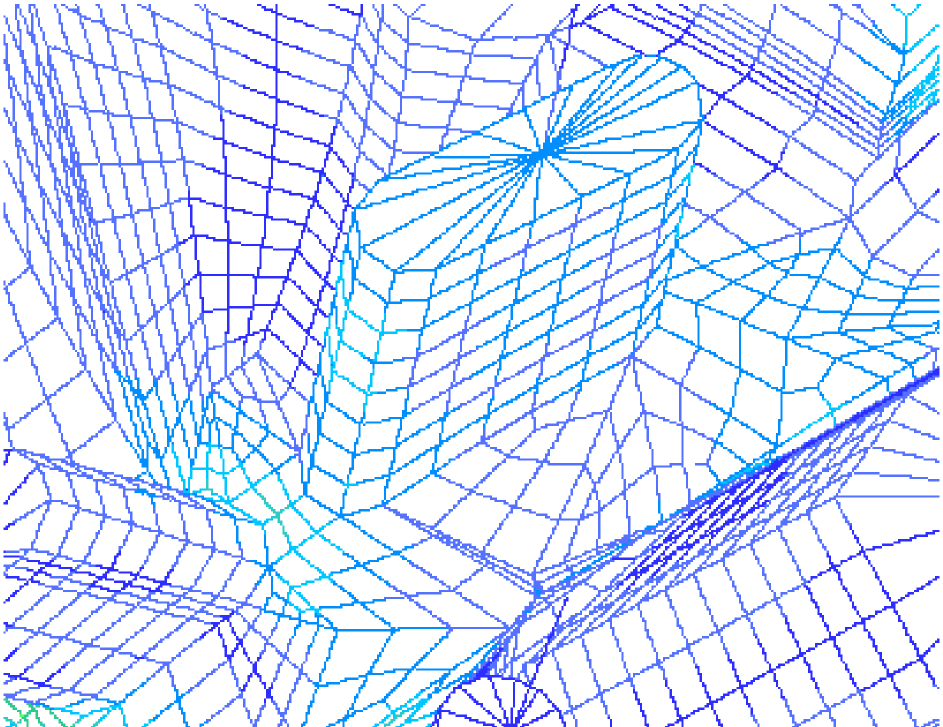
During the postprocessing, the indication of the position of the extreme values is of basic interest. This information can be given independently upon the chosen way of drawing (e.g. wireframe or hiddenline option) and is available for the interactive postprocessing as well as for the case of the reading from a postprocessing file completed some time earlier (metafile). If a zoomed region of the structure is desired, the extreme values will be shown as long as the position of these values lays within the drawing frame. Additionally, the extreme values of the displacements and the results will be written together with the correspondent nodes to the (interactive) output file to ensure a readability as clear as possible.

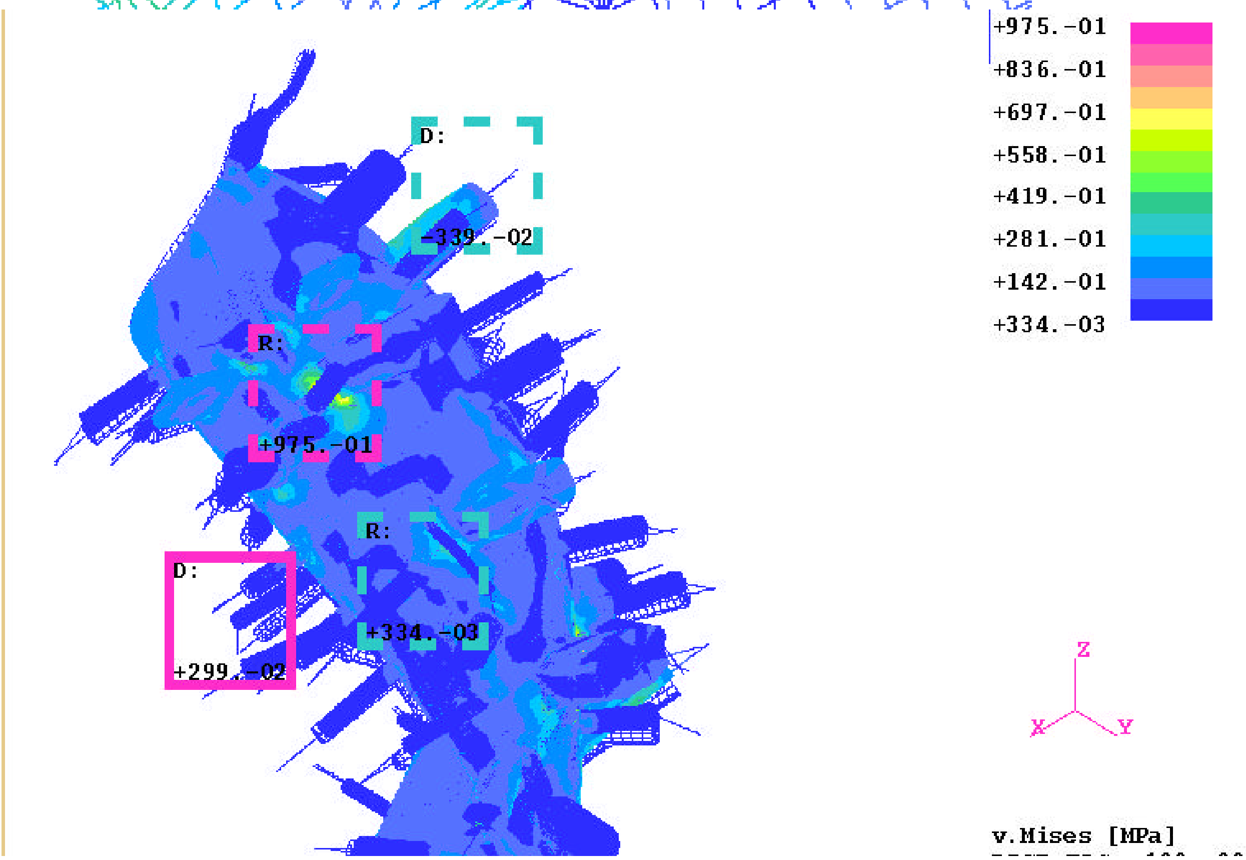
Figure 3 shows an example for a hiddenline illustration of the plasma vessel with the v. Mises results. The coloured result interpretation is a deformed drawing (chosen displacement multiplier: 100.) which lies over an undeformed drawing to get the impression of the magnitude and the kind of displacements.

In addition to figure 3, figure 4 illustrates a zoomed postprocessing of the same results to identify the surface area affected to the maximum value. It can be seen, that the high stressed area is small compared to the global surface of the plasma vessel. With respect to the yield limit of 270 MPa and the small affected area, the safety of the structure is high enough according to this load case.

Evaluation of local peak stresses

During the postprocessing, the results of the FE-calculation will be assigned to a correspondent colour so that each element surface can be evaluated. Since it is possible to get a fraction of the element areas affected to a certain result level (e.g. the result values within the range of the red of the colourbar) compared to the totality of all postprocessed areas, a table can be generated which indicates the different result levels (according to the colourbar) to the fraction




+975.-01
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v.Mises [MPa]

As an example for the result interpretation of the xy-stress component, the region of the plasma vessel containing the maximum is shown in figure 5. On the left side of the colourbar, the values indicate the xy-stress levels according to different colours, a second column at the right refers to the shape of the stress distribution which is illustrated simultaneously (special option) by the thickness of the colourbar. This kind of result presentation is very helpful for the validation of FE-models and for discussions with respect to questions of safety.

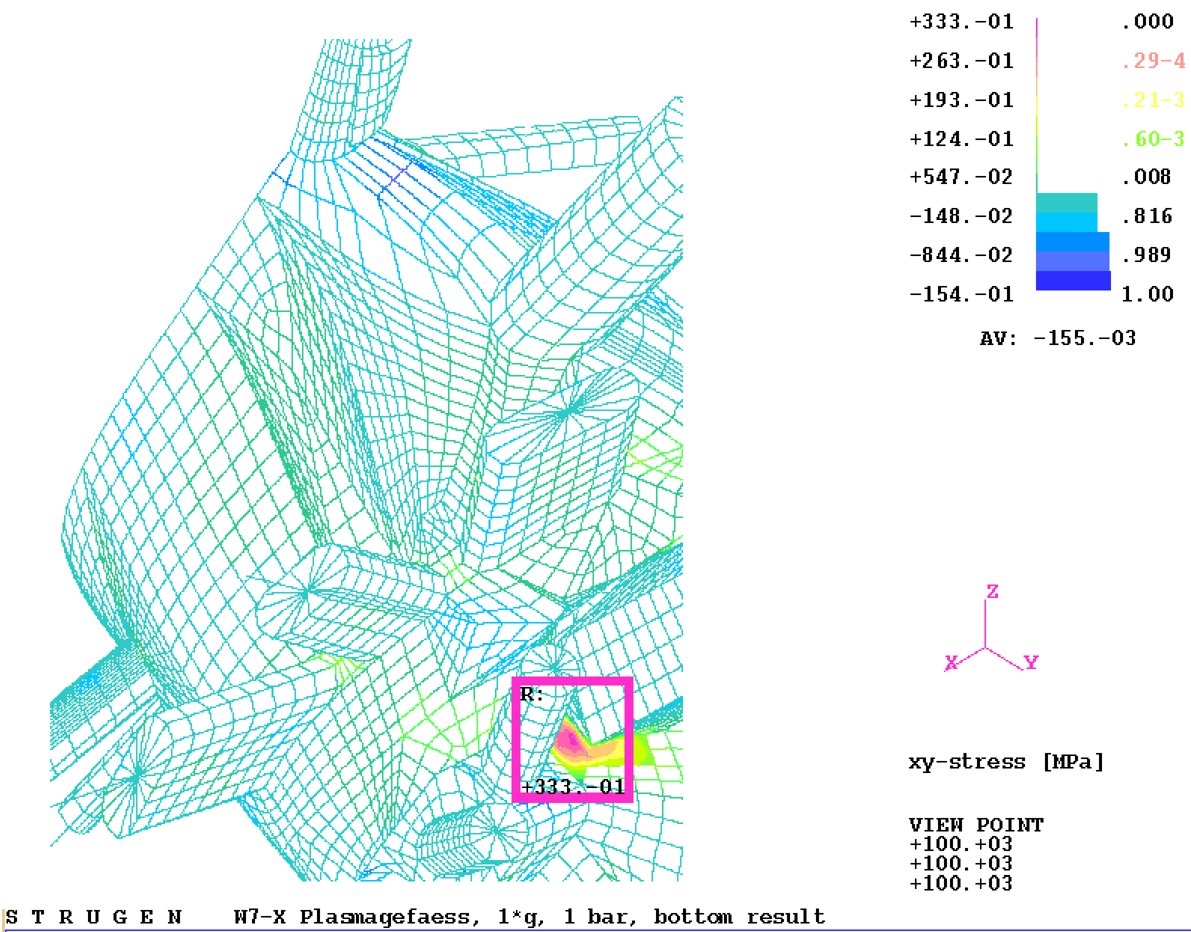


Figure 5. Stress distribution of the xy-stress component within a section of the plasma vessel. The first row at the colourbar refers to the colour range of the stress levels, the second row (at right) refers to the fraction of affected element areas starting from 1 (100%) at the minimum to 0 (0%) at the peak of the stress. The option is applied to assign the shape of the stress distribution to the thickness of the colourbar simultaneously.

Application of new materials for safety requests

The manpower needed to build a FE-model, to generate the necessary load cases, to make the iterations including corrections and the interpretation of the results requires a valuable time. Sometimes we have the situation, that new materials are coming into discussion when the computations have been finished. Small chemical additives to steel charges can result in higher yield limits without any significant change of the modulus of elasticity. In this way it is possible, that new materials with improved yield limits (but unchanged E-modulus) are imposed instead of the original materials.

For the case of existing results of an earlier FE-data-set or of a correspondent postprocessing (meta) file, the substitution of new yield limits and the visualisation of the actual safety can be performed with ease. As an example for the evaluation of the xy-stress component of the plasma vessel, figure 6 shows the distribution of the result with an supposed yield limit of 270 MPa, so that the factor of the maximum xy-stress of 33.3 MPa (to reach the yield limit) gives a safety value of 8.10 which is written below the colourbar.

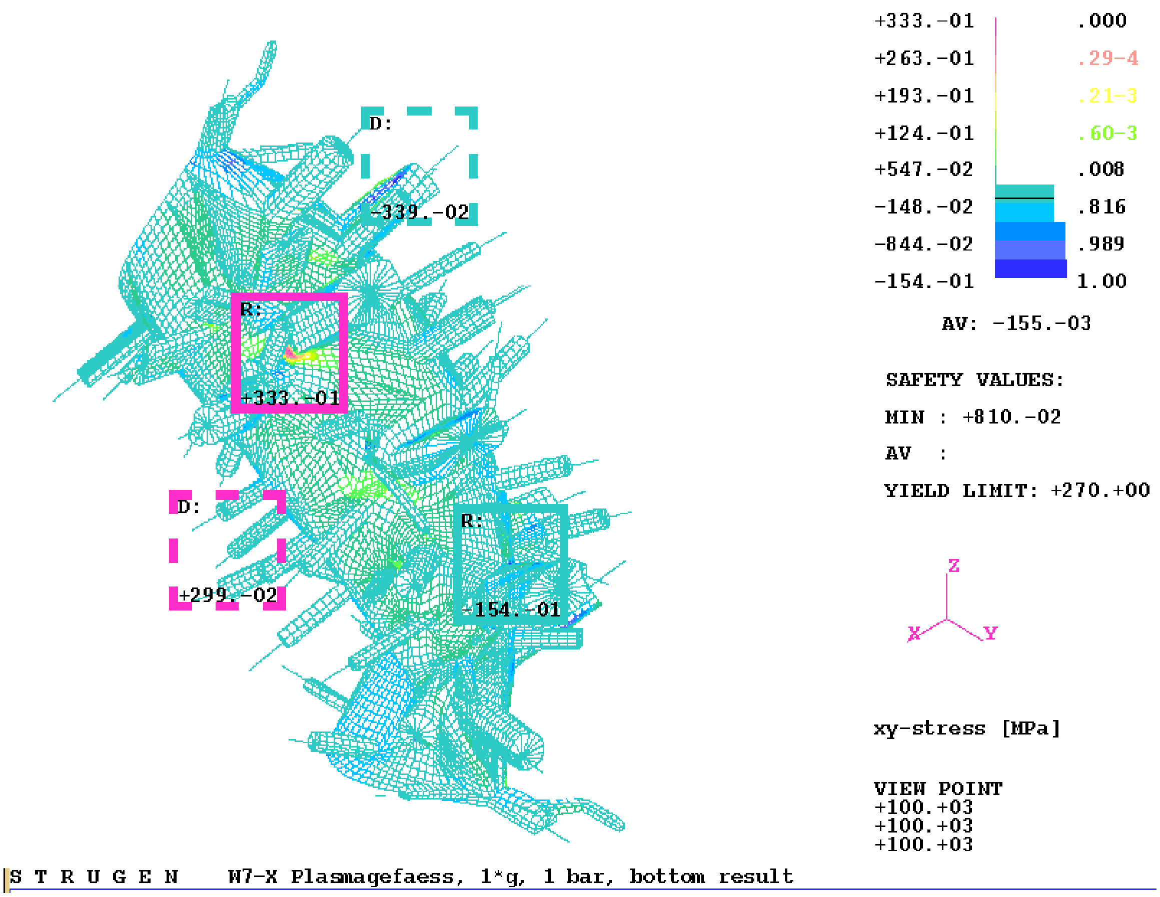


Figure 6. The plasma vessel with the xy-stress component as result. The substitution of 270 MPa as yield limit gives a safety value of 8.10. This option of the postprocessor is helpful for a fast evaluation of improved material limits.

Useful postprocessing options

In the context with the foregoing chapters some of the applied options are summarised here which are useful during the postprocessing:

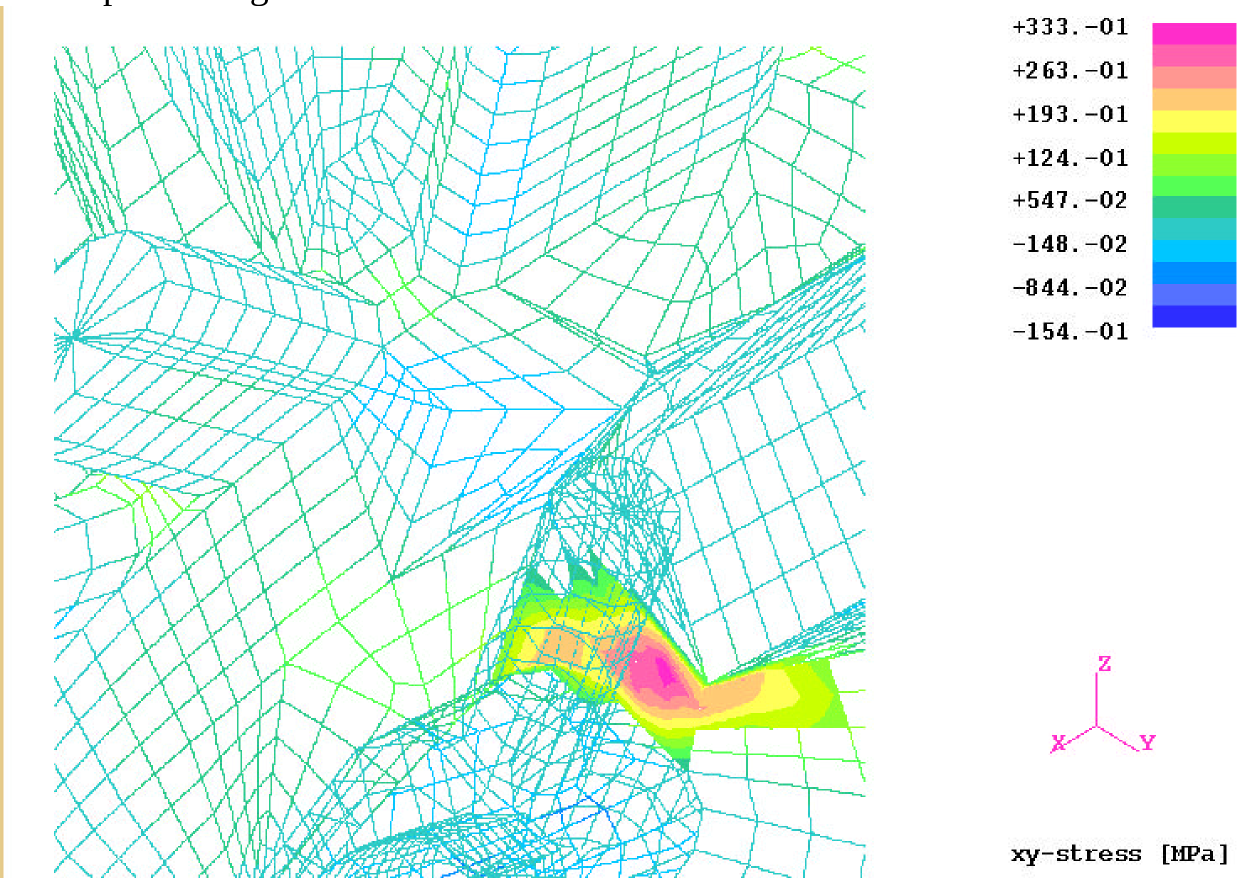
- any combination of hiddenline-/wireframe- illustration within a plot is applicable so that a view through the first wireframe surface is possible (figure 7).

- according to the first (or last) result levels of the colourbar, the automatic area fill option is applicable independent upon the hiddenline-/wireframe-illustration. This enables a fast and clear visualisation of the extreme results even in the case of a chosen wireframe drawing (figure 7).

- according to the result levels of the colourbar, the evaluation of the element areas affected to these levels may be performed. The shape of the function can be illustrated (by a correspondent shaped colourbar) to give a better understanding in which way the results are distributed over the structure (figure 5, 6).

- for the generation of a postprocessing file to illustrate the results some time later, activated options will be written on the file. Each generated picture can be drawn individually.

- the positioning of coloured boxes with the values of the extreme results can



Conclusions

The fast validation of an FE-model and its results requires additional options during the postprocessing which are presented here.

The safety evaluation of all static loads of the plasma vessel could be verified using the options described here.

The introduction of a second scale at the colourbar as an indicator of the shape of the peak stress leads to a better result evaluation.

The substitution of new yield limits of a material can be verified with ease, the documentation of the actual safety can be performed very fast.

Since most of these options are not available in commercial programs, special codes had to be written.

Additional Remark

With address to material scientists: The FE-programs offer the result interpretation of the complete stress tensor. To get a better feeling for a safety analysis, we would appreciate to get data of the material yield limits with respect to the different modes of rupture (figure 8) additionally instead of substituting the yield limit or energy based criteria only.

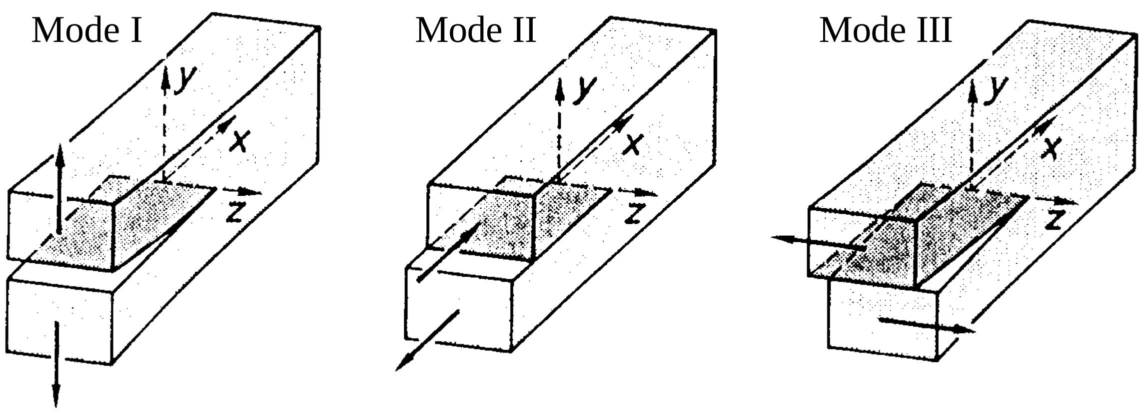


Figure 8. The three modes of rupture [4]. With respect to safety request, new data of the material limits according to these modes are appreciated.

References

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[3] J. Simon-Weidner, N. Jaksic, "Fast Evaluation of W7-X Components with Aspect of Safety Based on FE-calculations", pp. 823-826, Proceedings of the 20th Symposium on Fusion Technology, Marseille, France, 1998, Association EURATOM-CEA, Département de Recherches sur la Fusion Contrôlée, CEA/Cadarache, F-13108 Saint Paul Lez Durance CEDEX (France)

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