BE analysis of polygonal profiles shaft-hub couplings

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This work concerns a study on steel polygonal couplings, with trochoidal 3-lobe profile, and is aimed to highlight the contact stress and strain state of shaft-hub interface, with reference to particular profile geometric parameters. From Mechnik's and Kollmann's works, in which the analysis was performed by the Finite Element Method, this work develops a CAD/CAE methodology for coupling design, oriented to an efficient integration between CAD systems and Boundary Element solvers. The stress analysis is carried out with a Boundary Element code (BEASY) well suited for this kind of contact problems while coupling geometric model is made by Pro/ENGINEER, a solid parametric modeller.

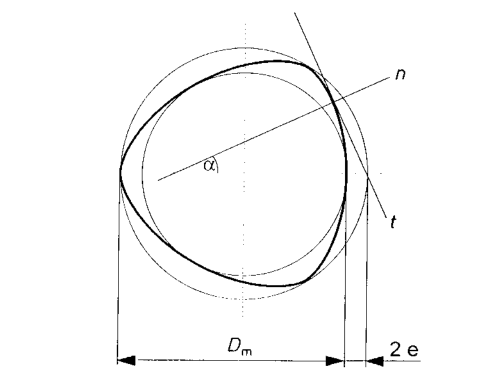
1. INTRODUCTION

In the mechanical transmission field, shaft-hub couplings with polygonal profiles play an interesting role because of their characteristics of self-alignment, lack of projecting elements and constructive compactness [1]. Nevertheless, these joints are very complicated and costly to manufacture because they require dedicated grinding machines and the stress analysis is very difficult due to triaxial stress state and lack of rotational symmetry. For a long time, these drawbacks have limited their use, discouraging design and production engineers to leave traditional connections based on keys and splined shafts. Nowadays, the development of numerical control grinding machines together with the improvement of hardware and software resources has allowed to reduce the above disadvantages, making the future of the polygonal couplings very interesting. Figure 1 shows a typical 3-lobe polygonal profile (included in the standard DIM [2]) with its characteristic parameters, such as D_m and e. Only recently a sufficiently detailed analysis of the stress and strain spatial state in shaft-hub joints has been proposed by Mechnik and Kollmann, using the Finite Element Method (FEM) [3-4]. From a production point of view, many drawbacks could be circumvented using Powder Metallurgy, which is well suited in the automotive field, especially for components subject to fatigue [5] and further development on polygonal profiles implementation is likely to involve such materials.

The authors point out a CAD/CAE methodology for coupling design, oriented to an efficient integration between CAD systems and BEM solvers. The aforesaid methodology is based on a synergetic and strictly integrated usage of the Pro/ENGINEER CAD system, for geometric model generation, and on the BEASY code for stress analysis.

2. CAD-CAE INTEGRATION

CAD systems and Boundary Element Method (BEM) work extremely well together because each uses identical geometric entities, such as points, lines, splines, circles and patches. The transfer of models among different CAx (Computer Aided Everything) systems often involves a lot of problems, related to the correct model data exchange because differences in database structure of CAx systems do not allow the direct data transfer to other engineering systems. The most used approach for CAD data transfer is the one based on neutral format. IGES (Initial Graphics Exchange Specification) appears to be the most used method of transferring geometric entities, although this approach has a drawback. IGES scrambles line and patch direction, while, inside a BEM solver, consistent entity direction is critical in determining the type of analysis, finite or semi-infinite, to be performed. Therefore the analyst must spend time adjusting the data prior to attempting an analysis. In general, however, moving data among engineering systems, by IGES or other translators, may cause loss or alteration of data, independently from CAD users' responsibility [6]. For example, accuracy errors may occur, because intersection curves between non-planar surfaces are approximated in most solid modellers. Preserving surface accuracy in the translation between different representations, such as Beziér, B-Spline or NURBS, will often require mapping a single surface into a collection of different surfaces in another representation. With regard to the aforesaid problems the following remarks are due: it is necessary to set up the same geometric accuracy in both engineering systems involved in the translation and to choose the proper parameters responsible for a correct surface/line translation from CAD format to IGES format. In our case, for the IGES model generation, all surfaces and curves have been converted in B-Spline entities (respectively 128 and 126 IGES entities).



$x = [D_m/2 - e\cos(n\alpha)]\cos\alpha - ne\sin(n\alpha)\sin\alpha$
$y = [D_m/2 - e\cos(n\alpha)]\sin\alpha + ne\sin(n\alpha)\cos\alpha$

Figure 1. Polygon profile with n=3 lobes

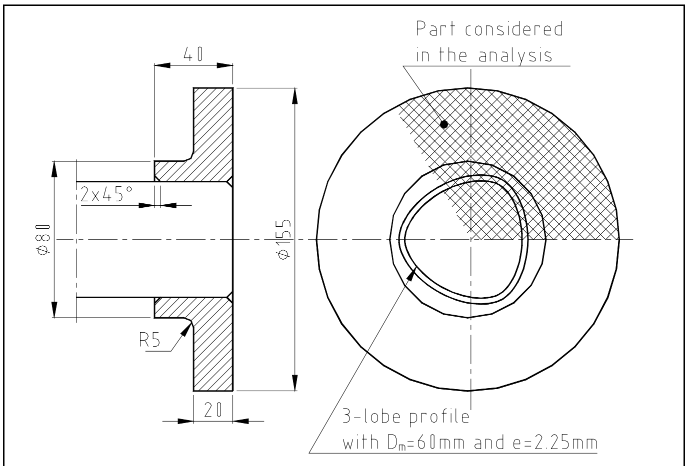


Figure 2. Polygonal coupling model

3. PROBLEM ANALYSIS

3.1. Problem description

Polygonal couplings with 3-lobe profile (Figure 2) made by steel are studied with a parametric CAD 3D system (Pro/Engineer R.17 by PTC) to build the coupling model while a structural analysis, together with pre and post-processing phase, are accomplished by BEM system (BEASY 7.0).

One cylindrical shaft end has been supposed to be clamped and the torque (M_t=1000 Nm) is introduced on hub contour by tangential forces (Figure 3). As already mentioned a BEM code has been used for the non-linear stress analysis and the convergence is obtained through an incremental-iterative technique: to follow the contact evolution, the load is gradually increased by few sub-steps and for each of them an equilibrium configuration is searched in iterative way, conditional upon compatibility normal displacement restraints [7]. The proper choice of the convergence tolerance, the maximum number of load sub-steps and iterations (respectively 1.5% , 15 and 15 in this case), is critical. A convergence study has been adopted on one third of the model with cyclic symmetry cinematic condition, and a mesh refining is mainly oriented to the high gradient contact area. In the final model 245 reduced quadratic elements (8 nodes) and 72 quadratic elements (9 nodes) have been used. Nine node quadratic elements are used in the interface area, where contact between shaft and hub cause very high stress gradient.

3.2. Analysis results

Figure 4 shows the deformed polygonal coupling in the contact area. Figure 5 and Figure 6 respectively show normal stresses and tangential stresses on the hub coupling interface area with reference to different values of z (axial distance of the section from the flange base). The contact surface is the most stressed, in particular with reference to the hub part. It is well evident that the results obtained through an h-p convergence study, are in agreement with FEM results from Mechnik [3], even if there is some discrepancy (<10%) of tangential stresses in the contact area. Actually, further convergence studies should be done with regard to reduced values of the "normal convergence tolerance" (it is not yet possible to customise this parameter in the BEASY code), in order to avoid the few "hot spots" still existing in the contact area but not affecting the overall results.

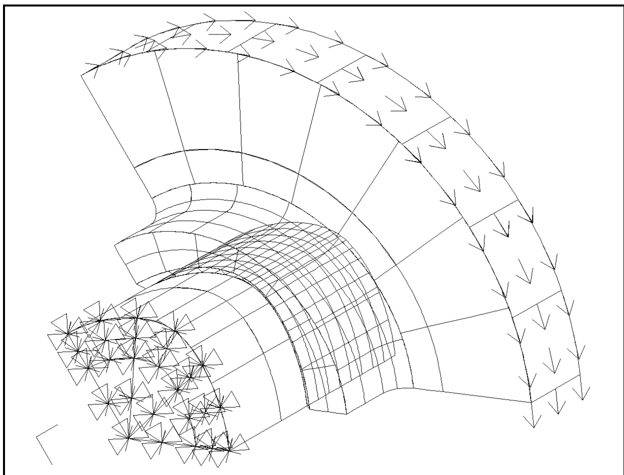


Figure 3. BE polygonal coupling model

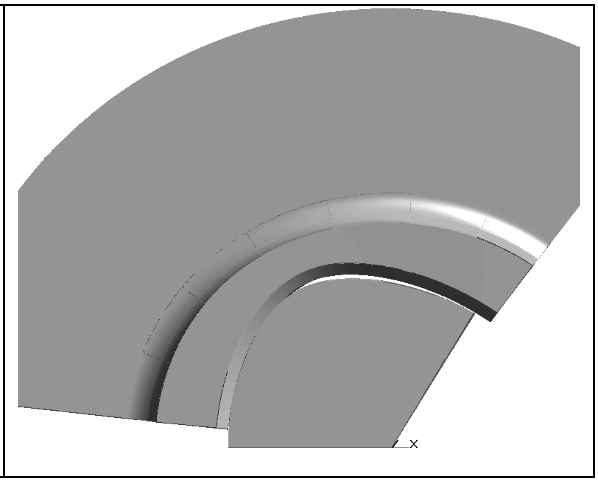


Figure 4. Deformed polygonal coupling

CONCLUSIONS

CAD/CAE integration has been realised with success, getting good convergence results and positively confronting all the problems related to data exchange among different systems. Even if the CAD/CAE procedure has been tested with reference to traditional steel (because a reference solution was available only for this materials) the future perspective is turned to sintered steel. With these materials polygonal couplings are expected to exhibit the main advantages, from a manufacturing point of view and with reference to fatigue load. With the previously described procedure, shape optimisation problems could be solved in a very efficient way because BE methodology is characterised by very low pre-processing times, effectively balancing longer run times in respect to FEM [8].

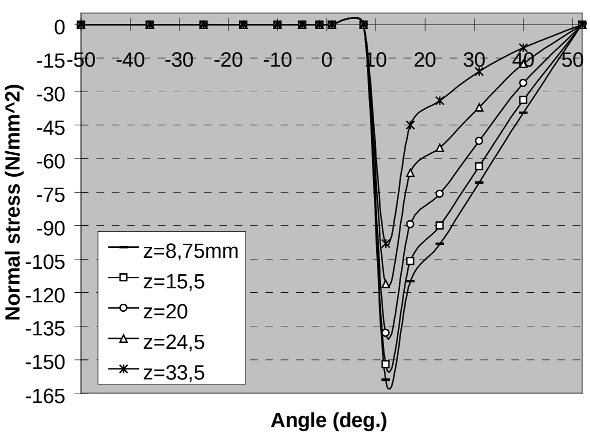


Figure 5. Contact normal stress by BEM

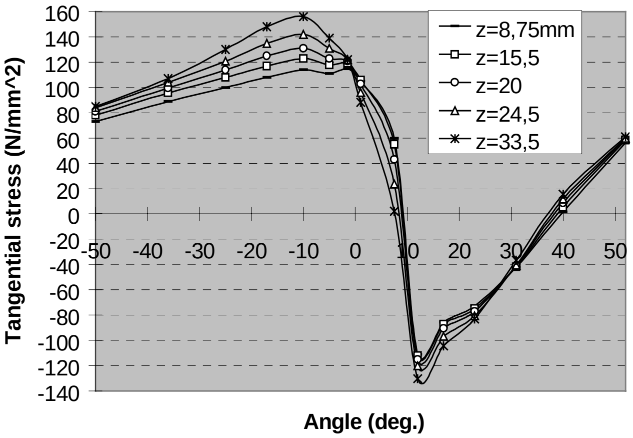


Figure 6. Contact tangential stress by BEM

REFERENCES

1. P. Orlov, Fundamentals of machine design, MIR Publishers Moscow, vol.4, pp. 69-73, 1980.
2. DIN 32711, Antriebselemente Polygonprofile P3G, 1979.
3. R.P. Mechnik, Beitrag zur Festigkeitsberechnung von Polygon-Welle-Nabe-Verbindungen unter reiner Torsion, Konstruktion, 43, 1991.
4. F.G. Kollmann, Chr. Göttlicher, Entwicklung einer verbesserten Festigkeitsberechnung für P3G-Polygon-Welle-Nabe-Verbindungen beikombinierter Biege- und Torsionsbanspruchung, Zwischenber, DFG-Forsch. vorhaben Ko 634/34-1, TH-Darmastadt, 1992.
5. F.J. Esper, C.M. Sonsino, Fatigue Design for PM Components, EPMA, Old Bank Building, Bellstone, England, 1994.
6. S. Gerbino, S. Crocetta, C. di Martino, Data exchange in CAD systems: limits, solutions, perspectives, Proceedings of X ADM Conference, Florence, Italy, 17-19 September, 1997.
7. F. Cappello, Calcolo delle tensioni di contatto con i metodi degli elementi finiti e di contatto, Il Progettista Industriale, N.9, Novembre, 1996.
8. Sugita, T. Itoh, T. Abe, Honda R.&D., Engine component design system using Boundary Element Method, Society of Automotive Engineers Conference, Detroit, MI.