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**FINITE ELEMENT MODELING OF A CYLINDRICAL CONTACT USING
HERTZIAN ASSUMPTIONS**

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Introduction

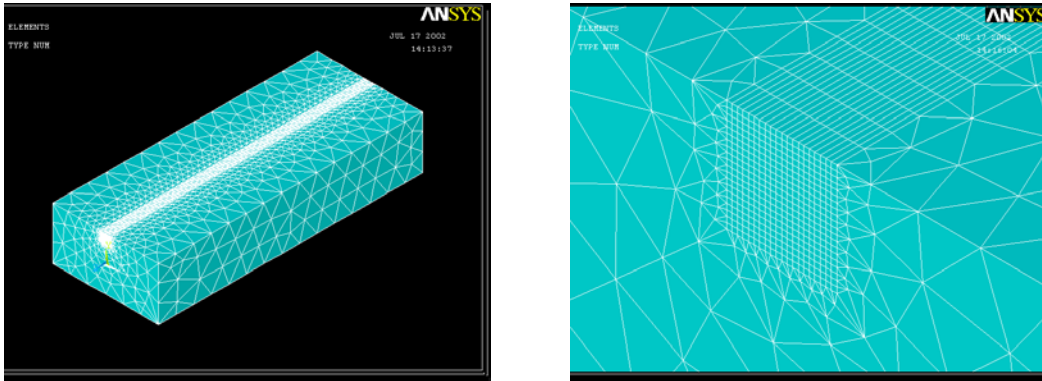
The turbine blades in the high-pressure fuel turbopump/alternate turbopump (HPFTP/AT) are subjected to hot gases rapidly flowing around them. This flow excites vibrations in the blades. Naturally, one has to worry about resonance, so a damping device was added to dissipate some energy from the system.

The foundation is now laid for a very complex problem. The damper is in contact with the blade, so now there are contact stresses (both normal and tangential) to contend with. Since these stresses can be very high, it is not all that difficult to yield the material. Friction is another non-linearity and the blade is made out of a Nickel-based single-crystal superalloy that is orthotropic.

A few approaches exist to solve such a problem and computer models, using contact elements, have been built with friction, plasticity, etc. These models are quite cumbersome and require many hours to solve just one load case and material orientation.

A simpler approach is required. Ideally, the model should be simplified so the analysis can be conducted faster. When working with contact problems determining the contact patch and the stresses in the material are the main concerns. Closed-form solutions for non-conforming bodies, developed by Hertz, made out of isotropic materials are readily available. More involved solutions for 3-D cases using different materials are also available. The question is this: can Hertzian¹ solutions be applied, or superimposed, to more complicated problems-like those involving anisotropic materials? That is the point of the investigation here. If these results agree with the more complicated computer models, then the analytical solutions can be used in lieu of the numerical solutions that take a very long time to process. As time goes on, the analytical solution will eventually have to include things like friction and plasticity. The models in this report use no contact elements and are essentially an applied load problem using Hertzian assumptions to determine the contact patch dimensions.

Finite Element Model and Formulation



Figures 1-2: From left to right; Finite Element Model and close-up of the fine mesh region

The figure above shows the small portion of the blade that would be touching the damper. Eight node brick elements comprised the dense region of the finite element model (FEM). The dimensions of each brick are 0.001 in x 0.001 in x 0.005 in. Very fine meshes are needed because of the applied load for this problem. A very large gradient is present, even over a thousandth of an inch. The applied load was determined by Hertz. It takes the form of a parabola and is applied along the surface of the model.

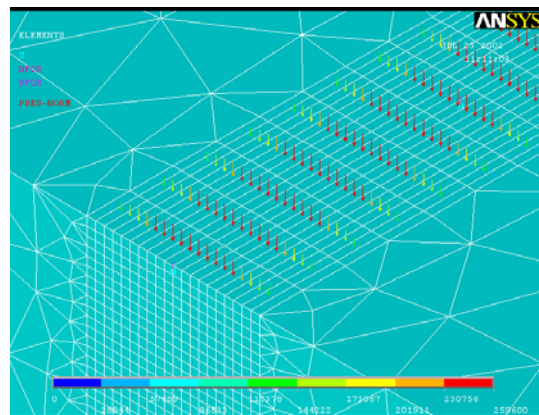


Figure 3: Parabolic Load Distribution

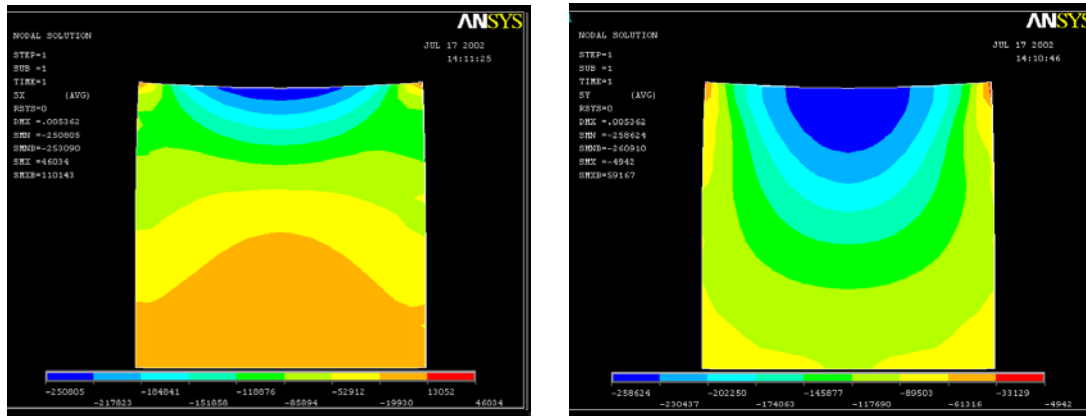
The colored arrows are the pressure applied to that particular surface element. Notice how the applied pressure (psi) starts at 0, but rapidly increases to over 100,000 psi in a just a few thousandths of an inch.

The model was constrained so no translation could take place in the direction of the applied load (Global Y-direction). A few other nodes were also constrained in the other two principal directions (X and Z) to provide stability. With the correct load, material

properties (single-crystal Nickel-based super alloy), geometry, and constraints in place the stresses were obtained using the ANSYS Finite Element software.

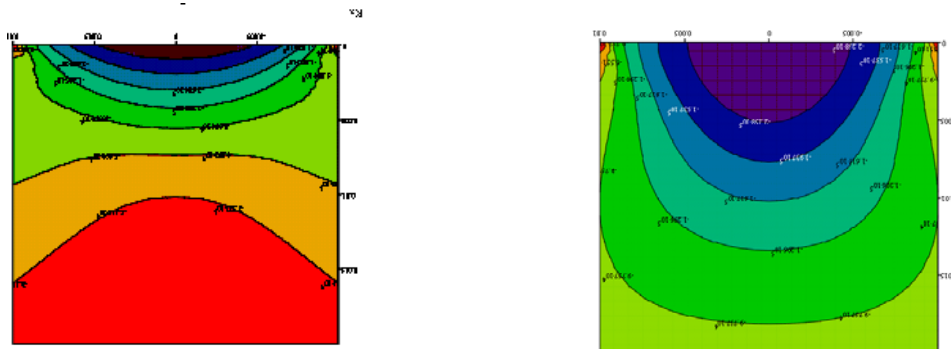
Results and Discussion

Single-crystal superalloys are not isotropic. The relative location of the crystal lattice (atomic structure) of the steel plays a vital role in the behavior of the material. Two sets of results are presented below, case 0² and case 33. In case 0, the crystal lattice coordinate system is parallel to the global material coordinate system. With case 33, the lattice is offset by a certain degree relative to the global coordinate system.



Figures 4-5: From left to right; contour plots (σ_x and σ_y) for case0

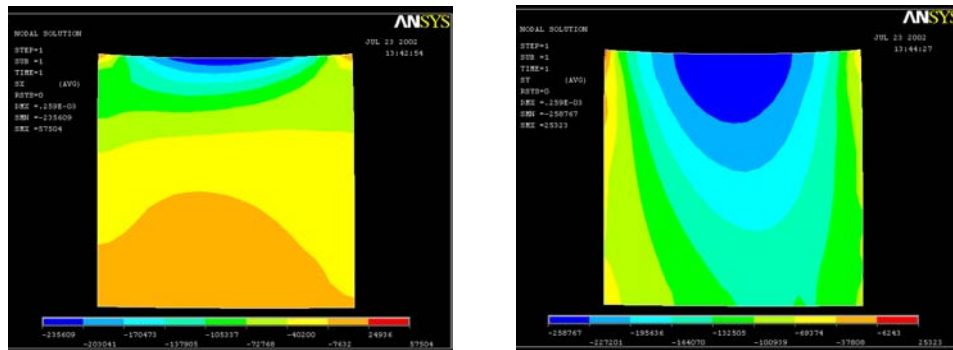
The stresses for case 0 (and for all other contour plots using this orientation) are symmetric. The above contour plot is the portion of the FEM that only contains the contact region. Outside of that region the stresses are uniform, which follows the predictions and analysis by Hertz. It was his contention that as one looks outside the contact zone, the stresses eventually become uniform. Thus, the primary area of interest is where the contact patch is and a few mills into the substrate (depth of the material).



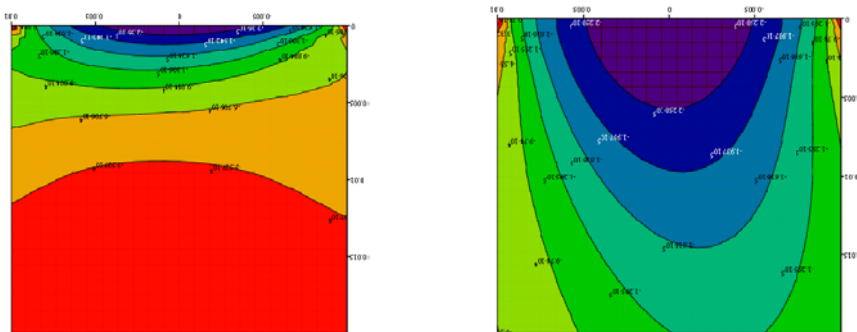
Figures 6-7: From left to right; contour plots from the analytical solution (σ_x and σ_y) for case 0

Nagaraj Arakere and Gilda Battista formulated an analytical solution, as this model was being developed, that complements the FEM. Note that in the above figure, the stresses are symmetrical just as the FEM contour plots are.

Looking at case 33, a case where the crystal orientation is now off-set by a certain degree, the contour plots are no longer symmetric, but the plots taken from the closed-form solution and the FEM look very much alike.



Figures 8-9: From left to right; case 33 contour plots (σ_x and σ_y)



Figures 10-11: From left to right; case 33 contour plots (σ_x and σ_y) from the analytical solution

Conclusion

From looking at the above two cases, the FEM and the closed form solution seem to agree rather well. The next step is to add the tangential load with friction and also try to compare those results with an analytical solution. Hopefully the results will agree and then the analytical solution can be used exclusively to solve this problem since it will be much faster than the large FEMs.

References

1. Johnson, K.L.: *Contact Mechanics*, Cambridge University Press, 1985.
2. Arakere, N.K.; Swanson, G.R.: "Effect of Crystal Orientation on Analysis of Single-Crystal, Nickel-Based Turbine Superalloys," NASA Technical Report 2000-210074, February, 2000.