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FUEL ROD TO SUPPORT CONTACT OPTIMIZATION FOR THE 16X16 NEXT GENERATION FUEL

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ABSTRACT

A detailed fuel rod-to-support model is developed to evaluate the contact shape between fuel rod cladding and grid spring and dimples. This modeling aim at optimizing the fuel rod-to-support contact for increasing the fretting margin during operation in the reactor. The fuel rod-to-support system is modeled with shell and contact elements, which is evaluated under fuel rod loading as well as under begin-of-life (BOL) and end-of-life (EOL) conditions in the reactor. The model is successfully tested against test data and solid modeling, what confirms the applicability of the method. The contact at the grid cross section and the shell element thickness reduction at the curve sections due to stamping process played a important role for improving the analysis results. The successful fuel rod-to-support contact shapes comparison for Finite Element Analysis (FEA) and test results shows that the developed methodology permits a reasonable fuel rod-to-support contact evaluation with basis on the contact pressures obtained from the model.

Keywords: Contact, Optimization, FEA, Fuel Rod, 16NGF

1. INTRODUCTION

16NGF (16x16 Next Generation Fuel) I-Spring Mid Grid Design is a grid with six-point rod support system consisting of two vertical springs and two horizontal dimple pairs per cell. Since, the I-spring design presents three convolutes in the longitudinal direction that bridges between two horizontally formed arches, the spring may present itself up to three contact points. The vertical spring is a I-spring design based on fuel assembly designs, which have successfully operated in the field (see Figure 1). The advanced features of this design include increased clad contact length with spring and dimples, which provide significantly reduced contact stresses and an improved wear depth to wear volume relationship, thus improving clad fretting performance. During the 16NGF rod-to-support optimization, besides a large contact area, the spring form must produce the design based load vs. deflection characteristics. In addition to that, there exist a potential for the center convolute of the spring to lose contact with the fuel rod, remaining the contact with sharp surfaces, thus increasing the potential for clad wear. Therefore, the procedure is evaluating and, if needed, optimizing the spring shape by using a finite element model before going to the confirmatory test, for a reduced fuel rod-to-support contact stresses over the deflection range of the spring, thus improving fretting wear performance.

2. METODOLOGY

In order to predict the 16NGF design spring shape, Finite Element Method (FEM) is used to simulate the deflection characteristics of the spring. The mesh is generated by the mapped option for the dimples, arches and spring, and by free option for the strap. The SHELL181 quadrilateral element is used for meshing. This element is well suitable for large displacements. The TARGE170 and CONTAC173 elements are used for the contact surfaces.

The mid grid cell-to-fuel rod model is shown in Figure 2. The boundary conditions as fixed are applied to the model tab welds.

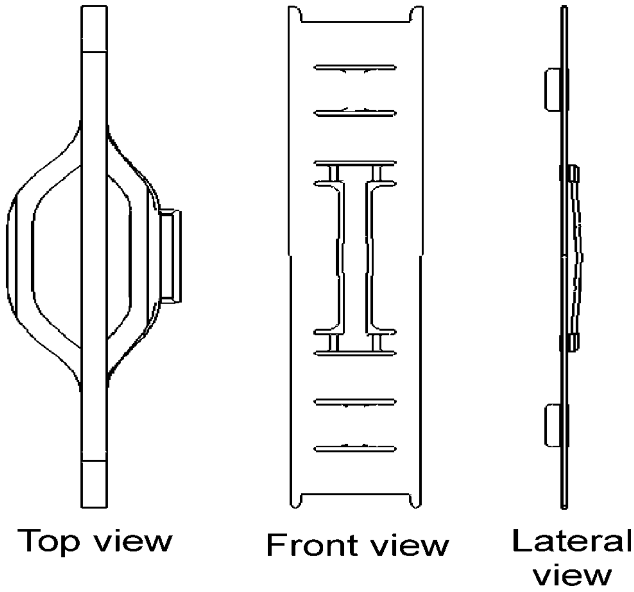

Figure 1 16NGF Mid Grid Cell Design Views

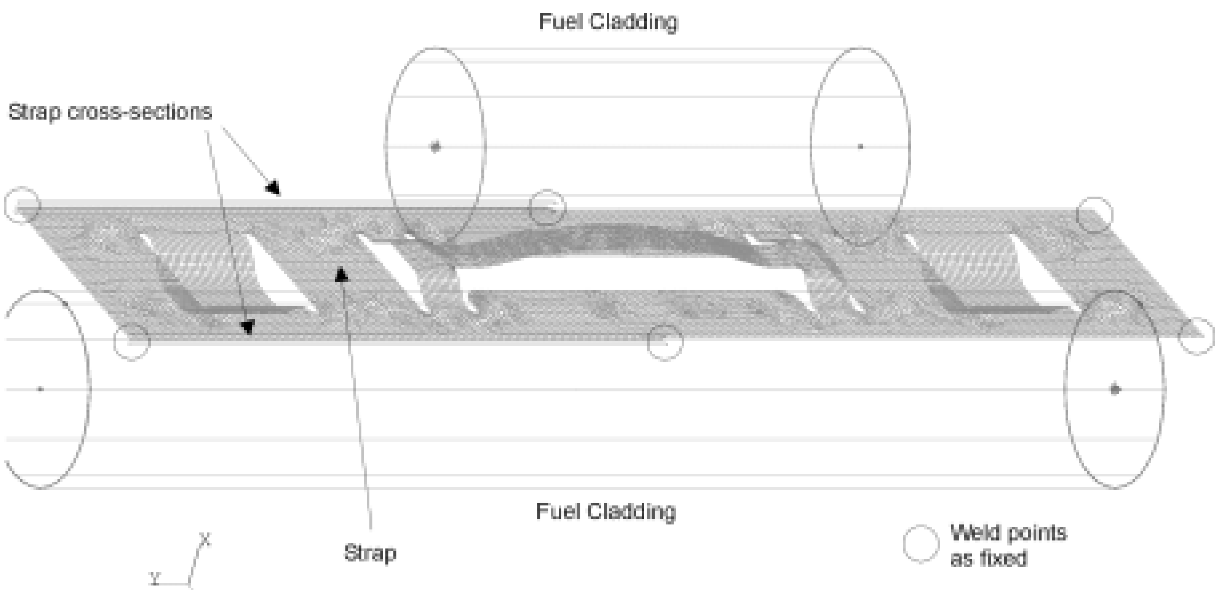

Figure 2 16NGF Mid Grid Cell-to-Fuel Rod FEA Model

In order to increase the accuracy of the predictions, it is determined that material thinning due to stamping process should be added to the model. Lab results from as built grid straps show that the thinning occurs on the radiuses of the arches and dimples. Thus, the effect of thinning is also incorporated into the model as shown in Figure 3.

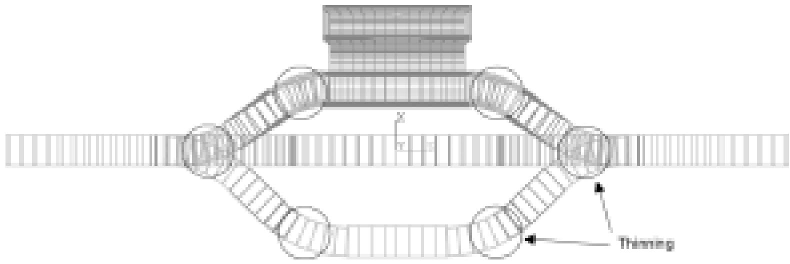

Figure 3 16NGF Mid Grid Cell FEA Model Detail with Local Thinning

3. VALIDATION

To ensure that realistic results are being produced by FEA, an existing spring shape is modeled and the results from this analysis is compared to the measured contact shape and profilometry results (see Figures 4 to 6). As it can be seen in Figure 4, the wear test results show only two wear scars on the fuel rod cladding. The same Figure shows the spring shape and the contact pressure related to the two contact points, both predicted by FEA. This is because, the center convolute looses contact with fuel rod during the spring deflection, remaining just the contact between the external convolutes of the spring and the cladding. Also, as it can be seen in Figures 5 and 6, the more the spring is deflected, the larger the gap opening is. However, it should be emphasized that the two external convolutes have sharper bending angles, what worsens the situation in terms of wear depth. The experimental and numerical results show that there is a good agreement between the spring wear shape and profilometry test results and those predicted by FEA.

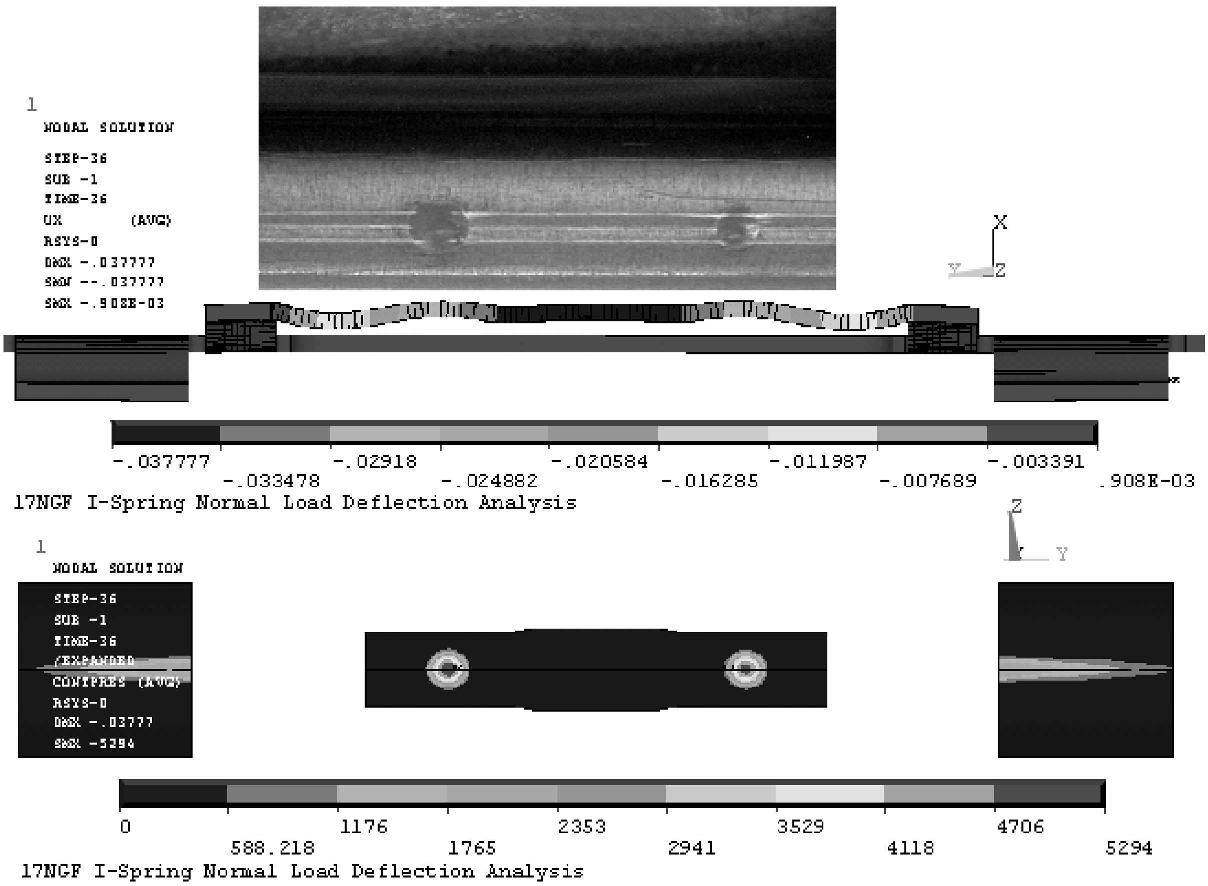

Figure 4 Existing I-Spring Wear Test Scars and FEA Model Results

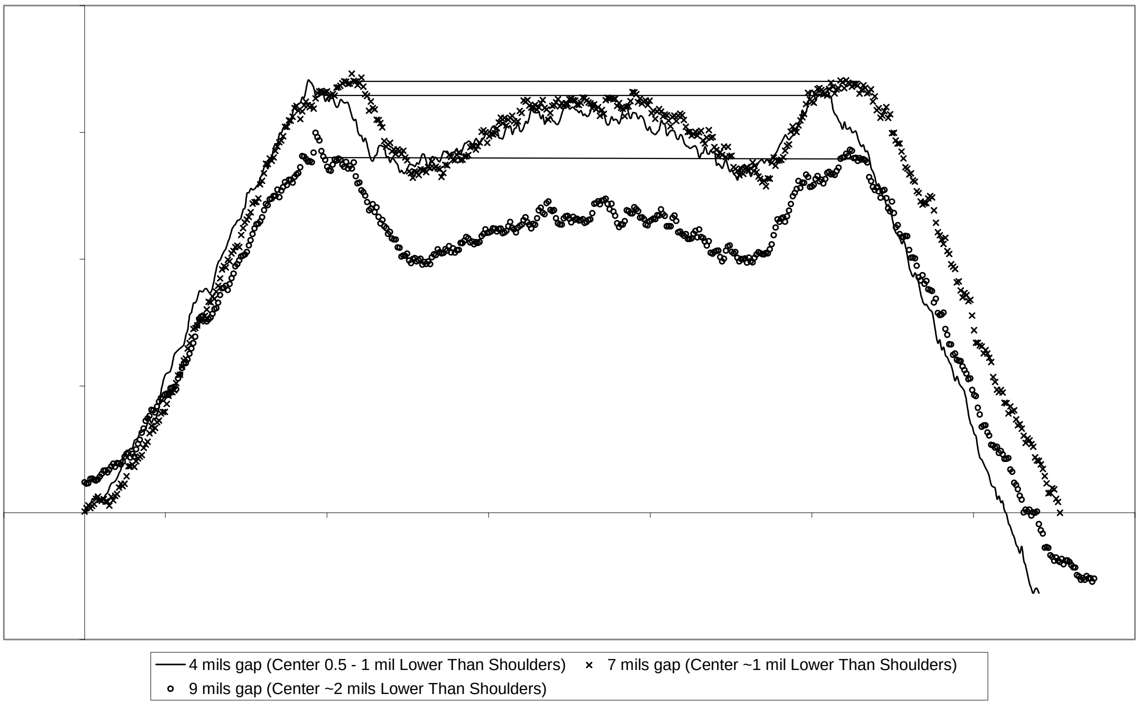

Figure 5 Existing I-Spring Profilometry of the Wear Test Scars

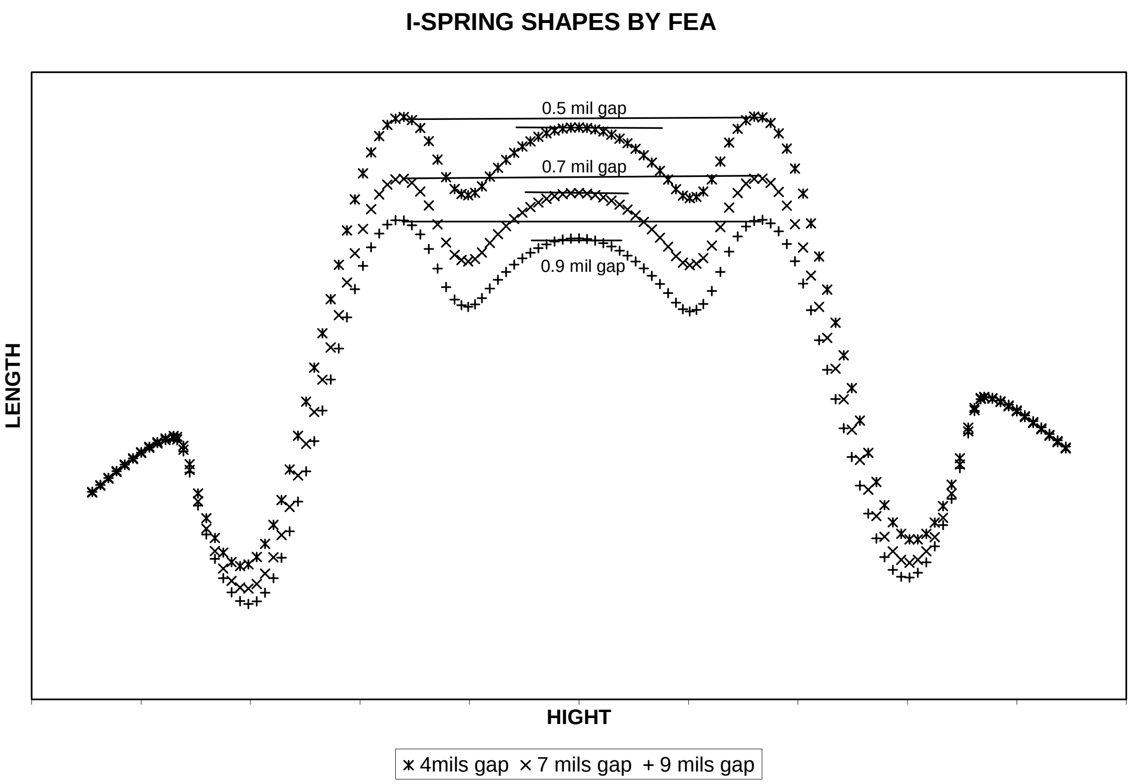

Figure 6 Existing I-Spring Shape Results Predicted by FEA

4. RESULTS AND DISCUSSIONS

Figures 7 shows the predicted spring shape of the 16NGF spring design for three deflection ranges by FEA. As it can be seen in Figure 7, the 16NGF spring design has a small potential for the center convolute to lose contact with the fuel rod as the spring is being deflected.

In order to have a constant contact between the center convolute of the spring and the fuel rod cladding for the entire deflection range, several cases with spring modifications are studied. The preferred spring modification is determined with a review of the contact length and pressure results predicted by FEA. Figures 8 and 9 show the spring shape and contact pressure results for the preferred case. For this case, the primary contact occurs on the center convolute. The contact pressures are also less for the chosen case compared to the as-built spring, resulting in lower rod contact forces and improved fretting wear margin. That is not only chosen based on contact but also on load-deflection behavior, which is another critical design parameter, and spring shapes.

The load deflection behavior from the as-built spring test is compared to the FEA prediction for the as-built spring profile and for the optimized spring (preferred spring) shape in Figure 10. The loading stiffness predicted by FEA for the current spring matches very well that obtained from the test. The FEA predicted loading and unloading stiffness for the chosen case are reduced by approximately 5%, which is still within the required cell stiffness range.

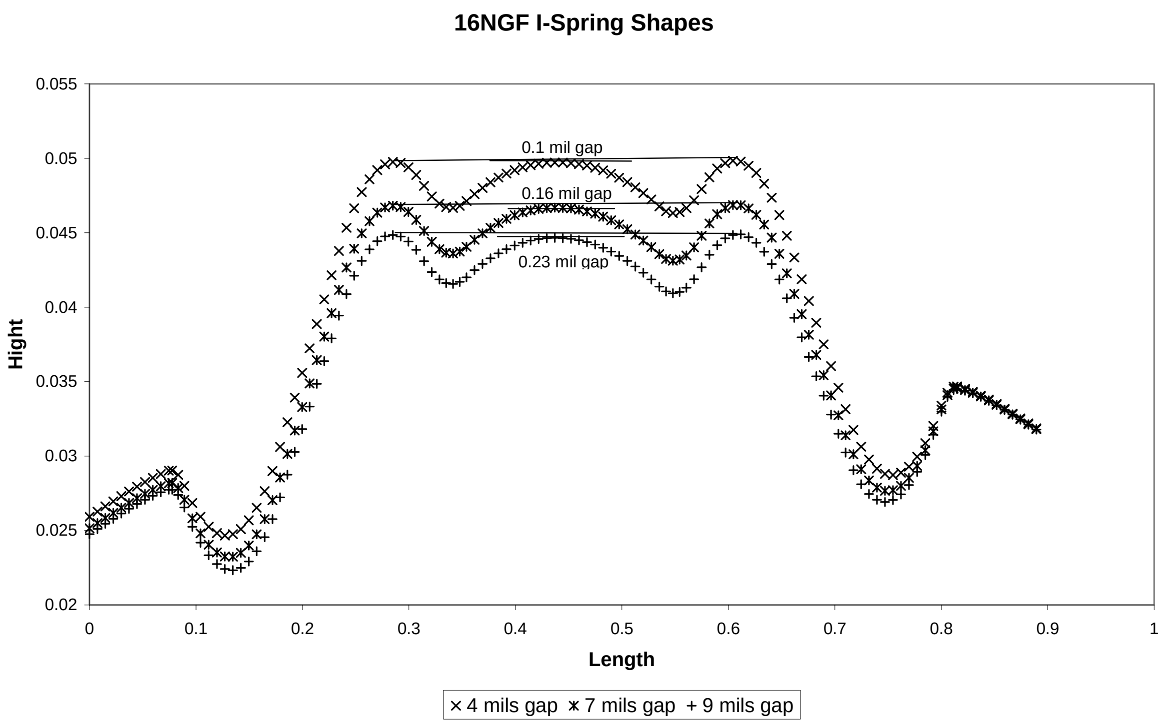

Figure 7 16NGF I-Spring Shape Results Predicted by FEA

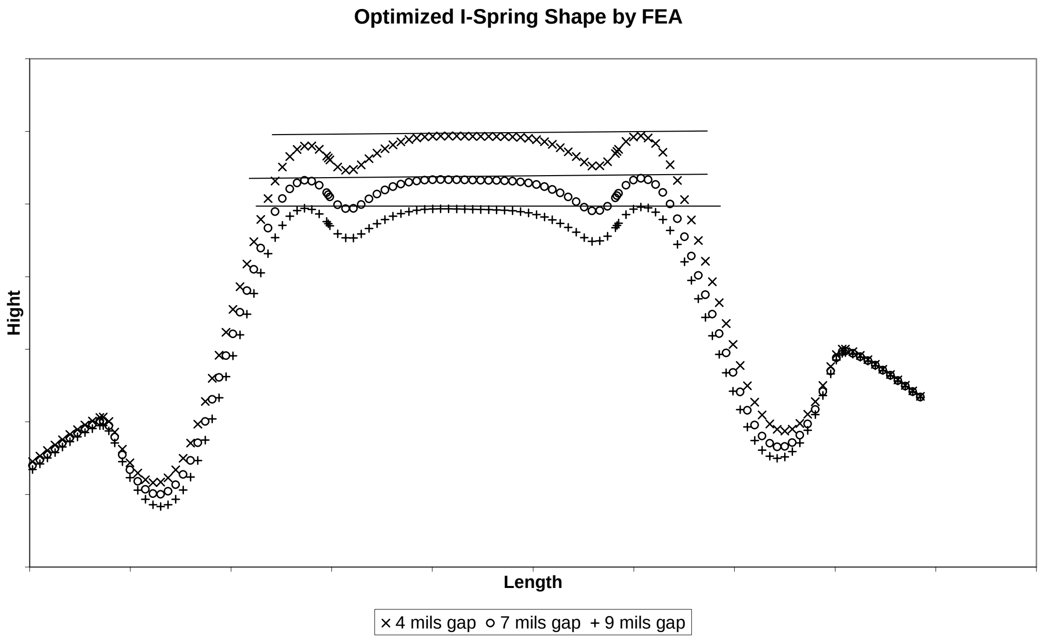

Figure 8 Optimized 16NGF I-Spring Shape Results Predicted by FEA

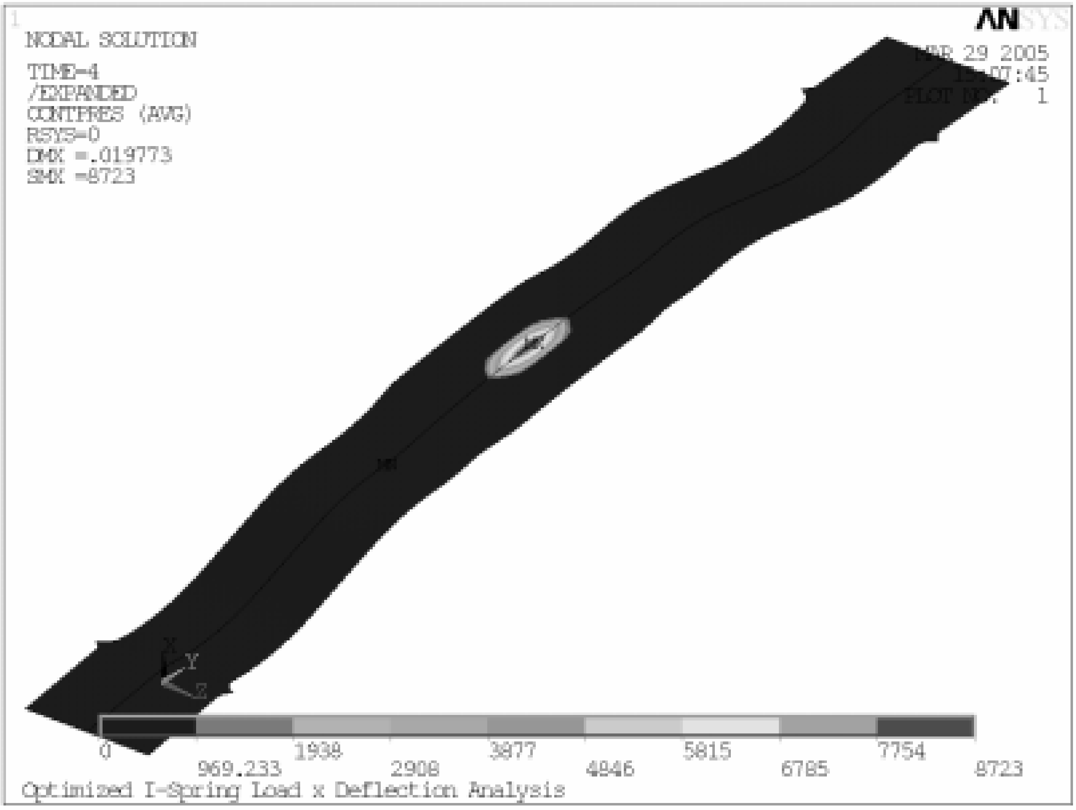

Figure 9 Optimized16NGF I-Spring Contact Pressure Results Predicted by FEA

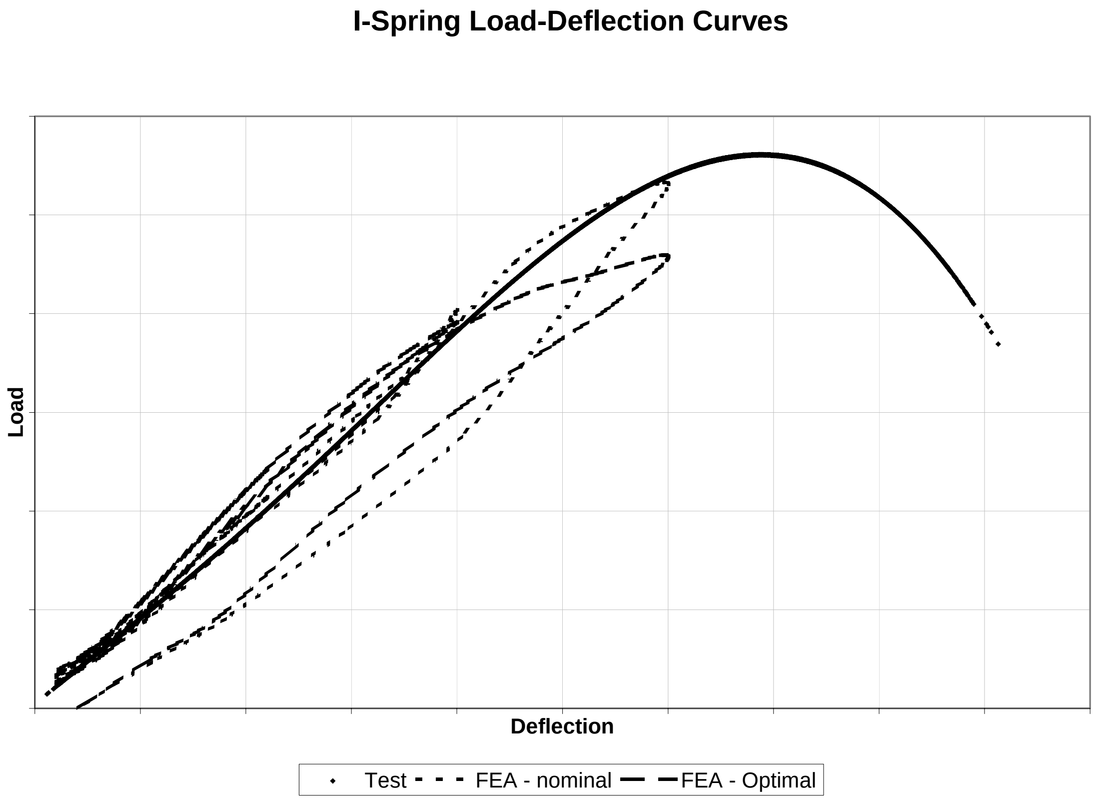

Figure 10 16NGF I-Spring Load-Deflection Curves – Comparison of Test and FEA Results

5. CONCLUSIONS

Among several cases studied, the best rod to spring contact shape for the modified spring shape is chosen. When compared to the test results, those of the developed FEA model match very well the experimental data. Hence, it can be concluded that several grid spring designs can be evaluated with basis on this methodology before going to the confirmatory test. It reduces significantly the design costs. Being able to quickly perform repetitive optimizations, the methodology above can lead to improved safety and reliability of fuel rod-to-support design that have developed fretting wear.

ACKNOWLEDGMENTS

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