Analysis of Non-linear Spring Characteristics of Holddown Springs

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ABSTRACT

The holddown Spring is one of the major components of a fuel assembly for PWR. It holds the fuel assembly firmly seated down on the lower core plate and allows the FA axial movement caused from the irradiation growth of guide thimbles. Depending on the up-lift force of a fuel assembly, from 2 to 4 leaves are assembled to be a set of a spring pack and it is fixed on the frame of the top end piece by screw. The spring can deflect so greatly during operation that consequently it would have non-linear characteristics. It is important to know the characteristics exactly in the design of the FA, especially for the estimation of the performance of the FA. Here, the non-linear force-displacement of each leaf spring as well as the spring characteristics of a pack consist of two to four leaves are obtained by ANSYS. Large deformation and stiffening effect as well as friction between each leaf are included. The results from ANSYS were compared with those from the test, which showed a fairly good agreement with each other. Using this method, the characteristics of a spring set can be predetermined prior to the final decision of a spring dimension.

Considering the performance of the spring behavior, it is desirable that the spring set has a large linear displacement range in order not to lose the spring force. Thus, to make a spring set have a large linear range, optimization of the spring, mainly concerned the spring thickness and yield stress, are done. It is shown that the optimized spring set, which has even less than one leaf, could have the same spring characteristics as a normal set.

INTRODUCTION

The hold down springs(HDS), located at the topmost component of a FA, maintain the FA firmly seated on the lower core plate to resist the uplift forces that are caused from flow force. If the hold down force is not sufficient, FA can be lifted and lowered down which might cause an impact on the guide thimble and other components. Thus it is important for the HDS to produce a proper and sufficient hold down force during the operation of FA throughout its lifetime. The holddown springs are subject to being exposed in an irradiation environment and it is susceptible to be relaxed and creep. In order to design the springs properly some design parameters should be carefully considered and be determined for sustaining its proper holddown force and maintain its functionability.

Two types of springs are now widely used, one is leaf spring and the other is helical coil spring. The leaf spring has merits in that it occupies less space and assembled compact on the top end piece and yields a large spring force at a small displacement. However the stress distribution of the leaf is apt to be localized at a large deflection and it will result in a non-linear behavior. On the contrary, the coil spring is easy to design and manufacture, better in linear behavior than leaf spring, however it needs much space to produce the same spring force as the leaf spring. Most of Westinghouse type FA adopted the leaf spring and CE type FA use helical coil springs. Several leaves are assembled to be a set of spring pack according to the amount of the flow uplift force. Usually from two to 4 leaves are used to make a pack of spring.

In the design of the bent type holddown springs, it is not simple as for the uniform beam because it has bended regions and the thickness varies over the length and the friction between the leaves has to be considered.
The previous method used for the perdition of the characteristics of the HDS was found in [1,2], where the HDS are considered as a simple beam and applying the energy theorem, the characteristic was obtained. However it was only

applicable to the linear range. One empirical formulae was used for each leaf and the characteristic of each leaf was superposed to get the spring set[3].

Recently, computer technology was developed brilliantly and most mechanical problems seemed likely to be solved unbounded. Moreover the material non-linearity and large displacement problems as well as the stress stiffening effect can be included in the FEM. If design parameters are determined by the FEM, it is a much more economic and efficient way to design the HDS[4].

Here, the characteristics of the spring set composed of up to 4 leaves are predicted by using ANSYS with more accurate calculation and the results are compared with test results. The holddown springs considered here were straight type and bent type in shape.

Considering the stress distribution, shape optimization of a straight type leaf was done to give a larger linear range of the spring behaviors. As a result of the shape optimization, it turned out that a spring pack with two optimized leaves was almost the same characteristic as a spring pack with 3 straight leaves.

FINITE ELEMENT MODELING

One Leaf Spring

Prior to getting the characteristics of a spring set, one leaf spring was chosen to know how the boundary condition and loading method could affect the results. Figure 1 shows the designation of the different boundary conditions(BCs) and loading method. The boundary conditions of the bottom of the leaf were selected 3 cases. One of them was a bottom node of the leaf was constrained in the normal direction of the node(hinged) and the others were : the nodes located on the bottom line of the leaf were contacted on the rigid surface or rigid block. The loading may be applied as a nodal force loading or rigid block displacement loading. Figure 2 shows the finite element model of a leaf spring with bottom node hinged, loaded by rigid block on the top face of the bent leaf. Figure 3 shows the comparison of the spring characteristics using various boundary conditions and loading methods designated as in Figure 1. From Figure 3, the characteristics are grouped into 2 major groups. One group has larger characteristics and the other has lesser characteristics. The larger group consists of the displacement loading group (B,D,F) and the lesser group consists of the nodal force loading groups(A,C,E). Judging from the comparison of the case A and E, B and F, the boundary conditions of a nodal support seems not to affect the results as is the case of the loading methods.

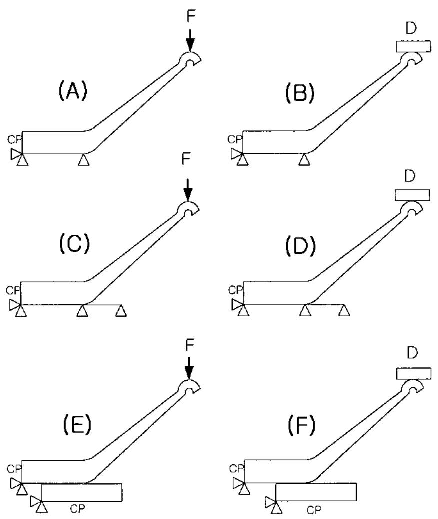


Figure 1 Boundary and Loading Condition

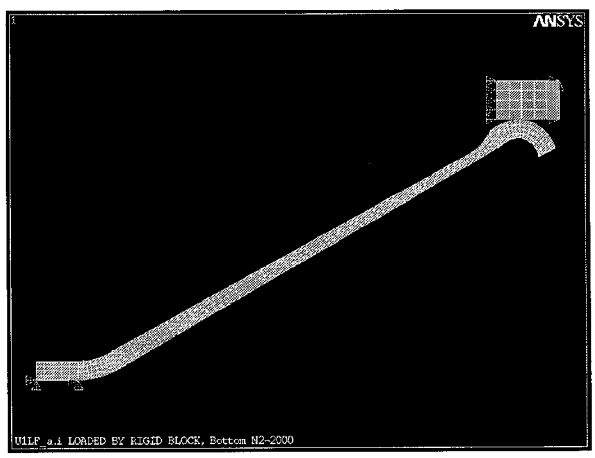
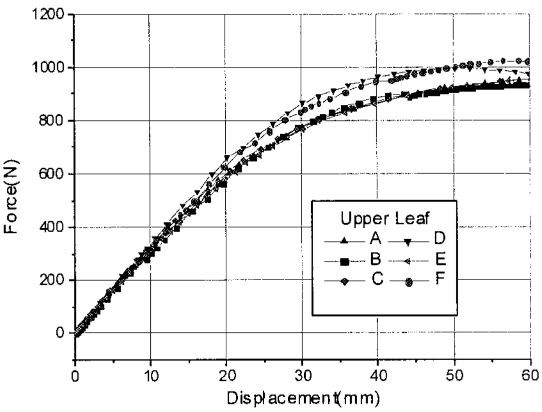


Figure 2 One Upper Leaf with Block Loading



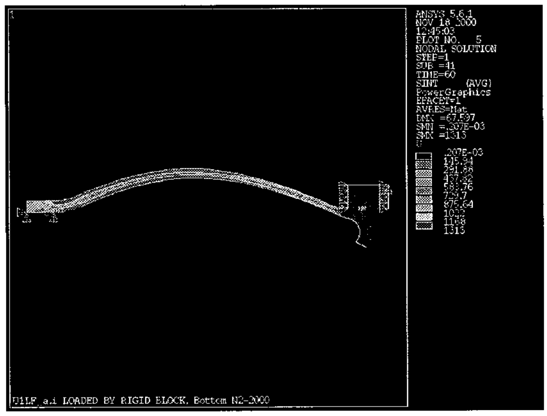


Figure 3 Spring Characteristics of Upper Leaf

Figure 4 deflected Shape and Stress

As the displacement of the spring become larger, the discrepancy of the characteristics of the two groups becomes greater. This can be explained by the fact that the moment arm of the nodal point loading becomes larger as the loading point moves outward as the displacement become greater. Figure 4 shows the deflected shape and the distribution of the stress in the leaf.

Springs Consisted of Assembled Leaves

Figure 5 shows the Finite element model of a spring set assembled with 2 leaves. The elements of the bottom nodes of the lower leaf mating with block are contact elements, which can be automatically given by ANSYS. Loading was applied by displacement of the rigid block on the top surface of the upper leaf spring. The nodes on the lower surface of the support rigid block were coupled with the displacement in x and y direction. The left most nodes of the leaves are fixed in x and y displacement in both directions. Figure 6 shows the deflected shape at the fully deflected condition with original shape. The spring characteristics of the spring set with two leaves are plotted in Figure 7 where the results of the spring characteristics obtained using the coefficient friction of zero and 0.3 between the leaves. The surface between the loading block and the top of the upper leaf also had a friction coefficient 0 and 0.3 for each case. From Figure 7 there seems to be no difference between the results with friction coefficient 0 and 0.3. This was because the friction force occurred at the mating surface was negligibly small for this case.

Figure 8 shows the finite element model of a spring pack consisting of 3 leaves. Figure 9 shows the deformed shape of the model fully deflected with initial FEM. Rigid Block displacement was applied on the top of the upper leaf on this model. The stress distribution is shown in Figure 10. The characteristics of this model are shown in Figure 11 with friction coefficient 0 and 0.3. Here the spring characteristics with the friction coefficient of 0.3 are slightly higher than that of 0.

The final case where 4 leaves are assembled to be a spring pack is shown in Figure 12. The 4 leaf spring pack was actually used for the 17x17 Korean Fuel Assembly. This model also loaded by rigid block displacement and the bottom nodes were mated with rigid support block as contact and target elements generated by ANSYS. Figure 13 shows the stress distribution of this model and Figure 14 shows the deflected shape. For this model, the characteristics were calculated using various loading cases. Figure 15 shows the results with friction coefficient 0 for various cases. Here model A designates nodal force loading with a bottom point hinged, Model B is rigid block loading with a bottom point hinged, Model C is a point nodal loading with bottom rigid block and Model D is rigid block displacement loading with bottom rigid block support. The results with the friction coefficient 0.3 are shown in Figure 16. From Figure 15 and 16, all the case is almost the same trend of the spring characteristics for each case and they are slightly higher than test results..

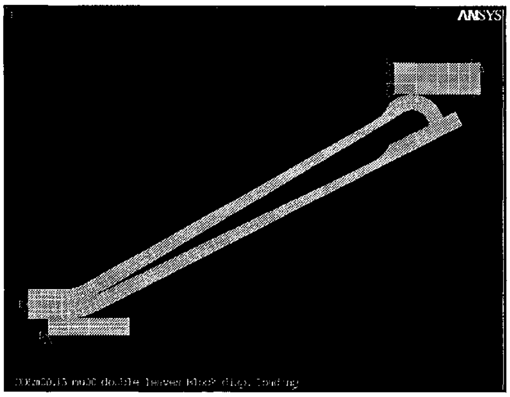


Figure 5 FE Model with Two Leaves

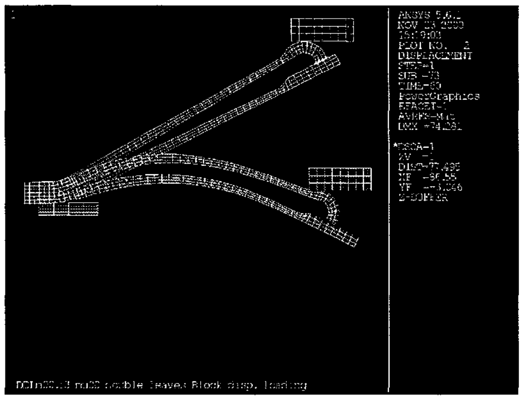


Figure 6 Deflected Shape of Two Spring

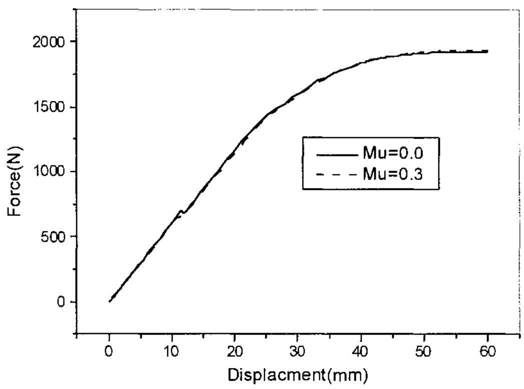


Figure 7 Spring Characteristics of Two Leaves

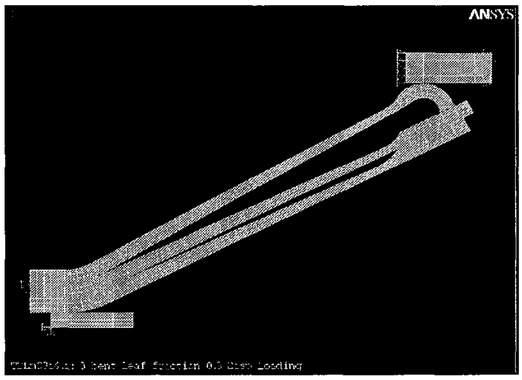


Figure 8 FE Model with Three Leaves

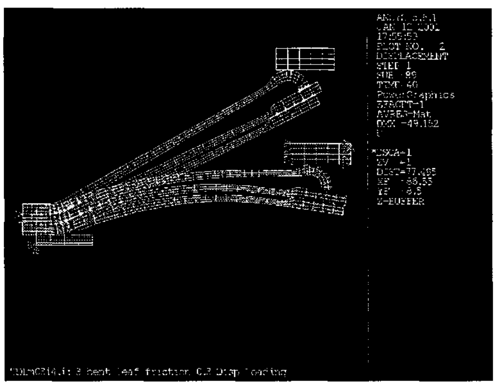


Figure 9 Deflected Shape of Three Leaves

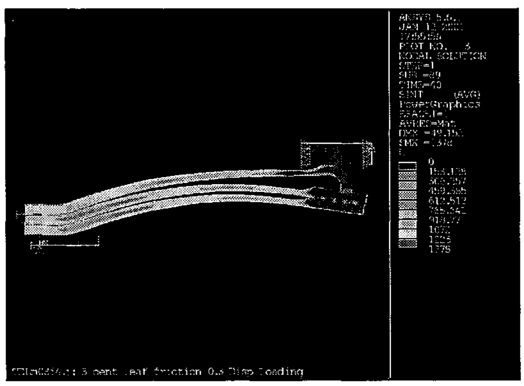


Figure 10 Stress Distribution of 3 Leaves

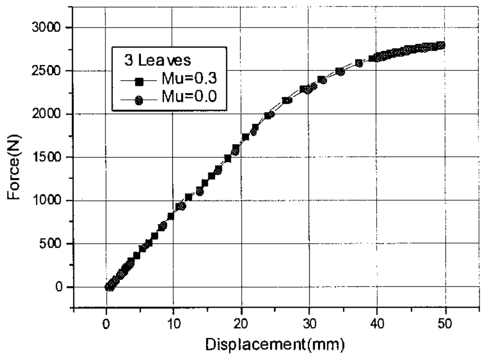


Figure 11 Characteristics of 3 Leaf Model

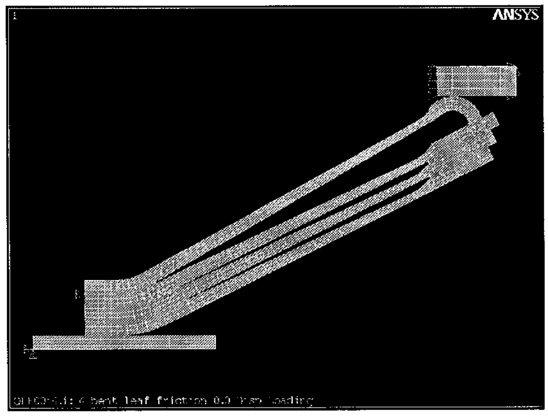


Figure 12 FEM with 4 Leaf Model

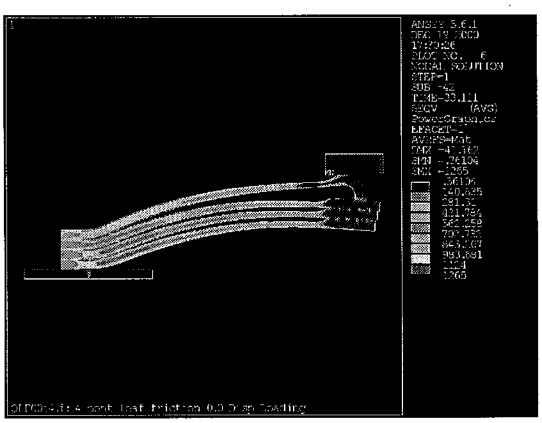


Figure 13 Stress Distribution of 4 Leaf Model

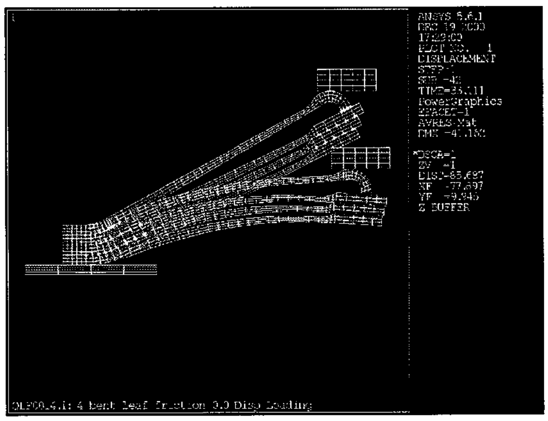


Figure 14 Deflection of 4 Leaf Model

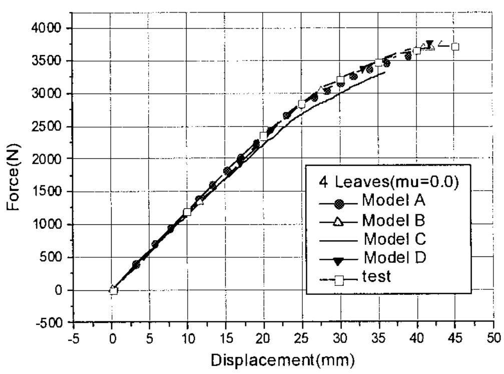


Figure 15 Characteristics of 4 Leaves(mu=0)

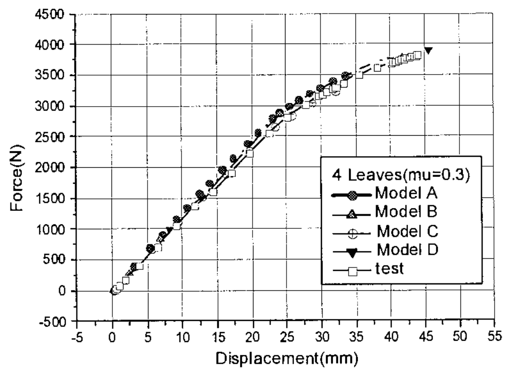


Figure 16 Characteristics of 4 Leaves(mu=0.3)

Straight Type Spring Set with Three Leaves

As the burn up of a FA extended, the axial growth of fuel rod is greater than the axial growth of the guide thimble. In order to avoid the fuel rod contacting the end pieces, it is necessary to allow more space between the end pieces. The easiest way to create more space between the end pieces is to shorten the end pieces, which requires a more compact holddown spring design. It was found in FOCUS[5] that the spring has straight type and becomes more compact in shape. Besides the compactness of the shape, the straight type HDS has better linear behavior of the spring. The spring pack consisted of a 3 leaf spring. For this type of spring pack, the finite element model is shown in Figure 17. Figure 18 shows the deflected shape of this model and Figure 19 shows the stress distribution of this model. The results with friction and without friction are plotted in Figure 20. For one point loading cases show relatively less spring characteristic at the larger displacement while the displacement loading case does not. In Figure 20 there is abrupt change of the spring curve. This is because of the occurrence of sliding between leaves due to the friction.

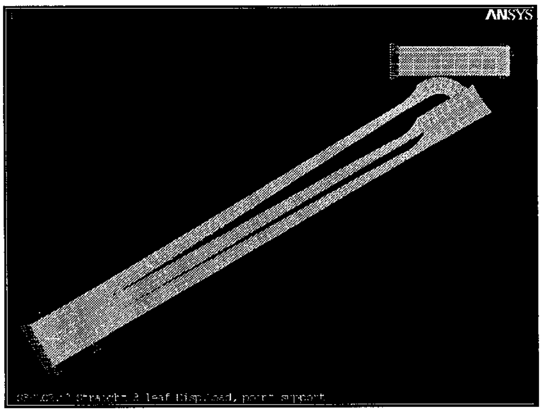


Figure 17 FEM of straight 3 Leaf Model

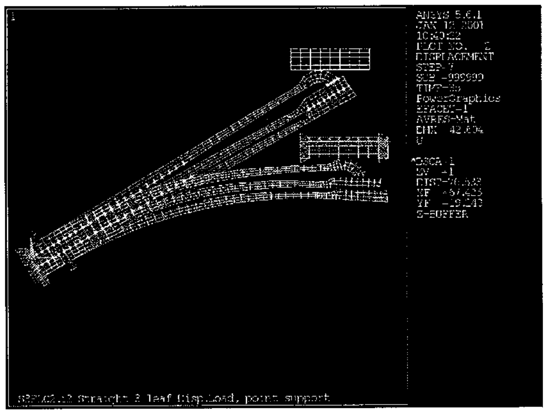


Figure 18 Deflection of Straight 3 Lf Model

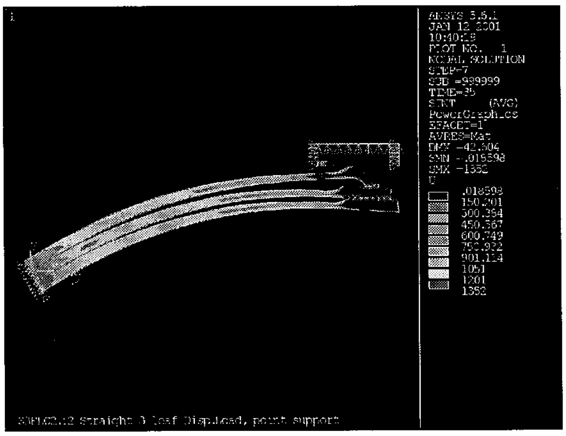


Figure 19 Stress Distributions of 3 Lf Model

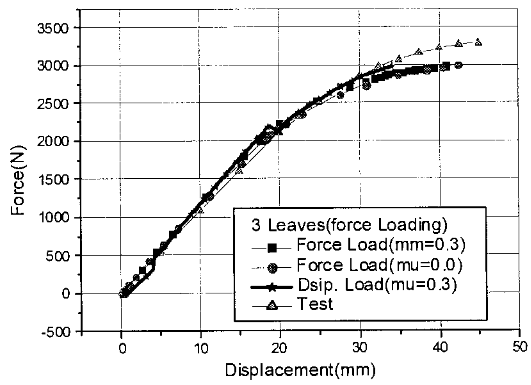


Figure 20 Characteristics of Straight 3 Lf Model

Optimization of the Spring Shape for the Straight Type Leaf

It was known from the stress distribution that the maximum stress occurred at the transition region of the leaf. And the high stress exceeding the yield stress resulted in a plastic state hence it has a non-linear behavior of the spring that must be avoided. Considering this point of discussion, shape optimization of a leaf was carried out to redistribute the stress level around the spring area. The ANSYS optimization routine was used for this calculation. The design variable was thickness and the difference of the maximum and the minimum stress was chosen as state variables, which must be at a minimum. The optimized results sets are shown in Table 1. One of the results chosen in Table 1 is set number 7 that is thickness 5.6mm and 2.1mm for the base and the neck of the leaf, respectively. Using this dimension, the results of a spring pack consisted with 2 leaves is shown in Figure 21. In Figure 21, the spring characteristics of a set with 2 optimized straight leaves are almost the same level of that of a pack with 3 straight leaves.

Table 1 List of Optimized Sets

	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	Set 8
H0	4.000	5.8123	3.7460	4.4190	4.1109	6.3334	5.5774	5.5390
H1	2.000	3.6001	4.4233	4.1617	2.9640	2.4519	2.1270	2.0352
Dels	98.498	97.203	358.34	207.75	195.30	76.025	42.242	35.452

H0 : Base Thickness(mm)

H1 : Neck Thickness(mm)

Dels : Status of the Objective Variables

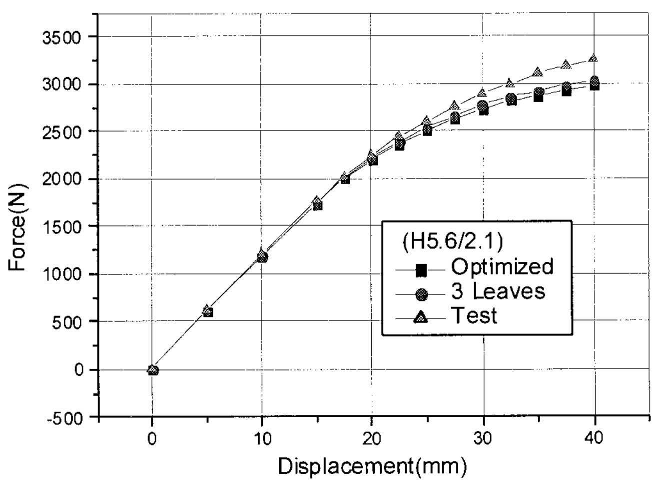


Figure 21 Characteristics of Optimized Spring

CONCLUSIONS and REMARKS

A spring set that consists of two to 4 leaves were finite element modeled and the spring characteristics were obtained. In the calculation, friction forces between each leaf and that of a block and leaf are included. Also different boundary conditions and loading conditions are taken into considered. First the calculation was done with a nodal force loading at the top of the spring. However it was proven that as the displacement of the spring precedes the loading point does not keep its normal position and it moves toward from the hinged point that results in a less spring characteristics. To simulate more accurately for this phenomenon, the loading method was changed to a rigid block displacement with contact and target element between the mating node between the block and the top of the leaf. The results with the loading by displacement showed fairly higher characteristics than that of the case of one point nodal loading method. While the rigid block support on the bottom node of the leaf does not affect much on the spring characteristics.

One of a straight type spring pack with 3 leaves were modeled and the spring characteristics were obtained and compared with that of a test result, which shows good agreement at the liner range. However at the larger displacement range, the calculated results using point loading showed less than that of test. It was shown that the results with displacement loading agreed better with the test results.

Finally the shape of a leaf was optimized to get better linear spring characteristics. With the optimized shapes of the spring, a spring pack with two spring leaves can produce almost the same spring characteristics as a spring set with 3 leaves.

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