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# Analysis of Nonlinear Curved Spring When Applying Nonlinear Load

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**Abstract:** A nonlinear curved spring has a free form shape. In this study, the curved beam is applied a nonlinear load, the load on the spring is pointed to a certain point of the space. This curved spring can be used in an orthosis. A certain load-deformation relation of curved spring which used in orthosis can assist the subject wearing the orthosis to climb the stairs. The analysis of the curved spring should be non-linear due to the applied load is a constant but its direction is point to a certain point. The deformation is hard predicted correctly for this spring. The purpose of this study is by using the Newton's method with ANSYS software to calculate the deformation of the spring. Finally, these results indicate that the Newton's method is efficacious to find the relation between load and deformation.

**Keywords:** curved spring, Newton's method, ANSYS software, non-linear analysis.

## 1 Introduction

The curved spring used in a lower-limb orthosis is an example of the usage of the curved spring as show in fig.1. [D. Shaw et al., 2009, and C. R. Huang et al., 2009] For a patient with osteoarthritis of the knee, in addition to medical treatment, he/she also needs to wear a lower-limb orthosis to lighten the knee joint burden, to improve the condition of the knee.

For the linear analysis, the direction of the load developed in the spring does not change [Chironis et al., 1961 and Guo-ping Xia et al., 2009] and the deformation is linear varied with external load. However, when the deformation of the spring is large during loading, even the load has a fix direction, the effect of nonlinearity is still needed to account on [C. V. Jutte et al., 2008 and Guy Biakeu et al., 2006].

Therefore, the purpose of this study is used the Newton's method and finite element method to calculate the relation between the load and the deformation of the

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structure. Finally, this results to compare with the deformation for curved spring. In addition, the curved spring's shape was based on Shaw's research [D. Shaw et al., 2009] to modeling. The configurations are shown in fig. 1.

Figure 1: Lower-limb orthosis with curved spring

## 2 Methods

This section consists of two parts: the first part refers to the simulation of curved spring and the second part refers to the experiment to measure the relation of load-deformation of curved spring.

### *2.1 Analysis of the Curved spring*

In this study, we assumed that the shape of the curved spring is as shown in fig2. The F($\theta$)t=0 is load along blue dash line direction at the beginning. The F($\theta$)t=1 is the load along pink dash line direction for next load step and the $\theta$ is the angle difference between the load direction of first and second step.

Flow chart of using Newton's method [Richard L et al., 2006] and the ANSYS to calculate angle $\theta$ is shown in fig3. The element type used in this study is the beam23, the mesh was divided into 201 nodes, the mechanical properties of material is stainless steel (SWPB): E = 194GPa and $\nu$=0.33 [Masayoshi Shimoseki et al., 2003] and the dimension of the diameter was assumed to be 5mm. The applying load is applied at the end of the spring as shown in fig.2. The direction of the load is based on $\theta$i which is determined by the angle between the directions of force of the first iteration and *i*th iteration.

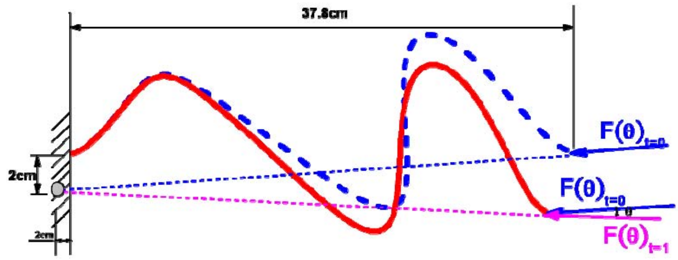


Figure 2: Boundary conduction of the curve spring

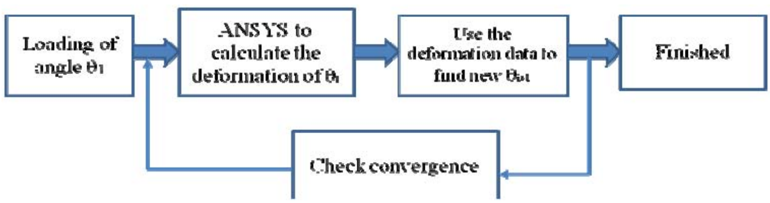


Figure 3: Boundary conduction of the curve spring

The processes of the iteration to determine the nonlinear deformation of the spring to a force which point to a certain point are as following. Step1: Assuming an initial force direction angle $\theta 1$. Step 2: Using ANSYS calculated the deformation of curve spring for $\theta 1$. Step 3: According to this deformation to find the new angle $\theta$i+1 of the force which should point to a certain point. Step 4: check if $|\theta i+1-\theta i|$ < 0.0001 to check the convergence of the results, if it is converged than complete the process.

### *2.2 Measurement of Load-Deformation*

The experiments were performed and the configuration of the experimental set up is shown in fig.4. A curve spring's shape was based on the Shaw's research. The load was applied at the end by a cable which starts from the right fixed point to left fixed point. A load could be applied on the left end of the cable. This configuration could apply a force of fixed direction. The magnitude of the load increased from 0 to 3 kg for every 0.5kg step as shown in fig5. A pulley was attached to the fixed point and 21 marks were used to measure the deformation of the curved spring. A plot of the deformation on a square paper for the each of 0.5 kg was made.

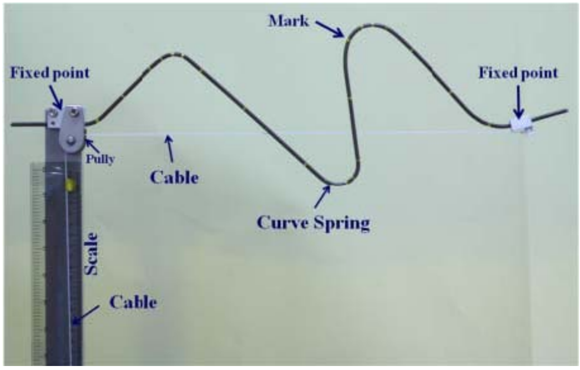


Figure 4: Measurement curve spring derive


Figure 5: The deformation of the curve spring for each increase of 0.5kg

## 3 Results

There are two analysis models to be analyzed, one is the model of CAD comes from Ref. Shaw and the other is the model same as the spring used in experiment. The reason for using two models is try to find the effect of manufacture error on spring deformation. Fig. 6(a) shows the measured deformation of the curved spring with the load from 0 to 3kg. The maximum deformation at the end of the curve spring is in the range of 20 to 40 mm. Fig. 6(b) shows the results of analysis of the curved spring CAD configuration proposed by Shaw by present method (ideal CAD model) and the load was from 0 to 3kg for each step increased 0.5kg. The maximum deformation also occurred at the end of the spring, and the deformation was in the range of 0 to 70 mm.

Fig. 7(a) shows the results of the CAD model, which was drawn based on curve spring, by present method and the load was the 0 to 3kg for each increment of 0.5kg. The maximum deformation occurred at the end, and this value is about 20 to 50 mm. This result indicates that the end deformation of the ideal CAD model was higher than the experiment results.

Fig. 7(b) shows the measurement deformation comparison between different model of spring and the experiment of the curved spring. The black line represents the shape of the curved spring without load; the red line is the shape of applying 3kg at the end of the CAD model's spring; the brown line is the result of the analysis of 3kg load by the same model as real spring; the green line is the results of 3kg load by linear analysis and the blue line is the results of 3kg load by non-linear simulation (The set up on ANSYS is the large deformation). This indicates that the deformation predicted by model of real spring was close to the measured deformation of the curve spring.

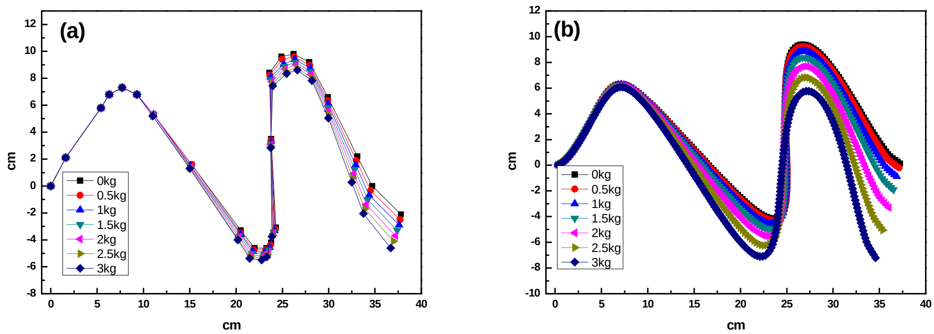


Figure 6: The deformation of curved spring and the load is applied at end (a) measured deformation of curve spring, (b) The results of simulation

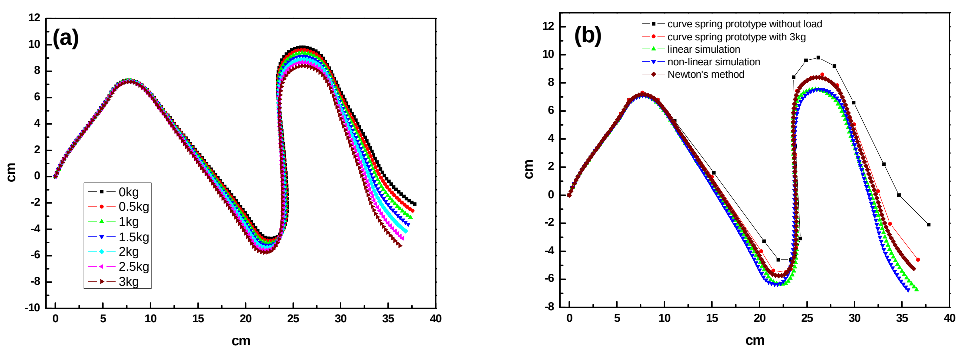


Figure 7: The deformation of curved spring and the load is applied at end (a) present method, (b) comparison of different method with measurement result

## 4 Conclusions

This research has the following conclusions:

1. Fig 7(b) indicates that the present method is good method to find the relation between the load and the deformation for the curved spring.
2. As shown in the fig.6, there is some difference between the curve spring and the ideal CAD model of the Shaw's research. It is estimated that this different deformation between experiment and analysis might result from the error of modeling.
3. In the future, we will further do the research by applying the incremental load. The process of study can also be utilized on other shapes of the curved spring.

**Acknowledgement:** The support of National Science Council (grand number NSC 96-2218-E-007-0005) is appreciated.

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