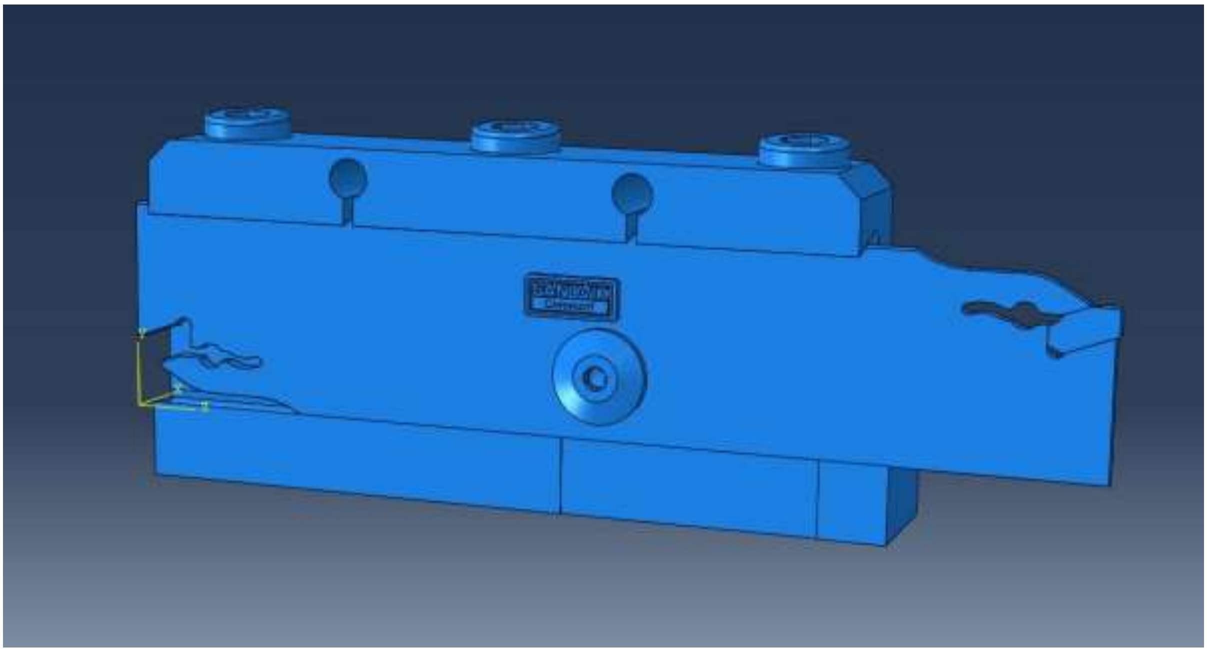
Structural optimization of parting off tool



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Abstract:

Different tool designs of the given parting tool were designed. The designs are evaluated based on the comparison of static and dynamic stiffness of the given and the optimized models. Lowest eigen frequency and volume of the tool are also considered. Topology optimization is used for satisfying the given objectives and constraints. Finally, the best optimized design is suggested.

Modal analysis is carried out for the given tool and the optimized tool for comparing the torsional modes and frequencies.

The influence of different overhangs of the tool on the performance of the tool is studied and a better overhang is suggested.

Contents

Introduction

Machine cutting include several types of operations like blanking, piercing, trimming, parting, etc. Press tools are commonly used for machine cutting processes in hydraulic, pneumatic, and mechanical presses to produce components at high volumes.

Parting operation is normally used to remove the finished end of a workpiece from the bar stock that is clamped in the chuck. Other uses include things such as cutting the head off a bolt. Parting uses a blade like cutting tool plunged directly into the workpiece to cut off the workpiece at a specific length. Parting is similar to grooving except that grooves are cut to a specific depth instead of severing a completed/part-complete component from the stock.

Parting off tool is generally thin blades of HSS, but there are also carbide insert tools available for the task. The carbide inserts are a bit wider than the tool to reduce the contact between the swarf and the tool while the chip is coming out. Rigidity is extremely important for design of parting off tools. Another important step is to make sure the tip of the tool is right on the center line of the piece that is parting off. Oil or tap magic water are used as lubricants for parting operation as it produces a lot of heat.

Problem Statement

The task is to design the parting off tool for machining operation with the following objectives and constraints.

The objective is to design a tool with high dynamic stiffness as possible without reducing the static stiffness.

The constraints of the problem are, the height and width of the tool cannot be altered. The position of insert should not be changed.

The following are the further tasks to be determined.

Designing the tool in such a way that the cutting edge is at nodal point for first torsional mode.

Influence of different overhangs of the tool on the performance of the tool.

Method

Structural optimization of the given tool is design is performed. For this, simulations are carried out in ABAQUS. The following is the algorithm performed in solving the given task.

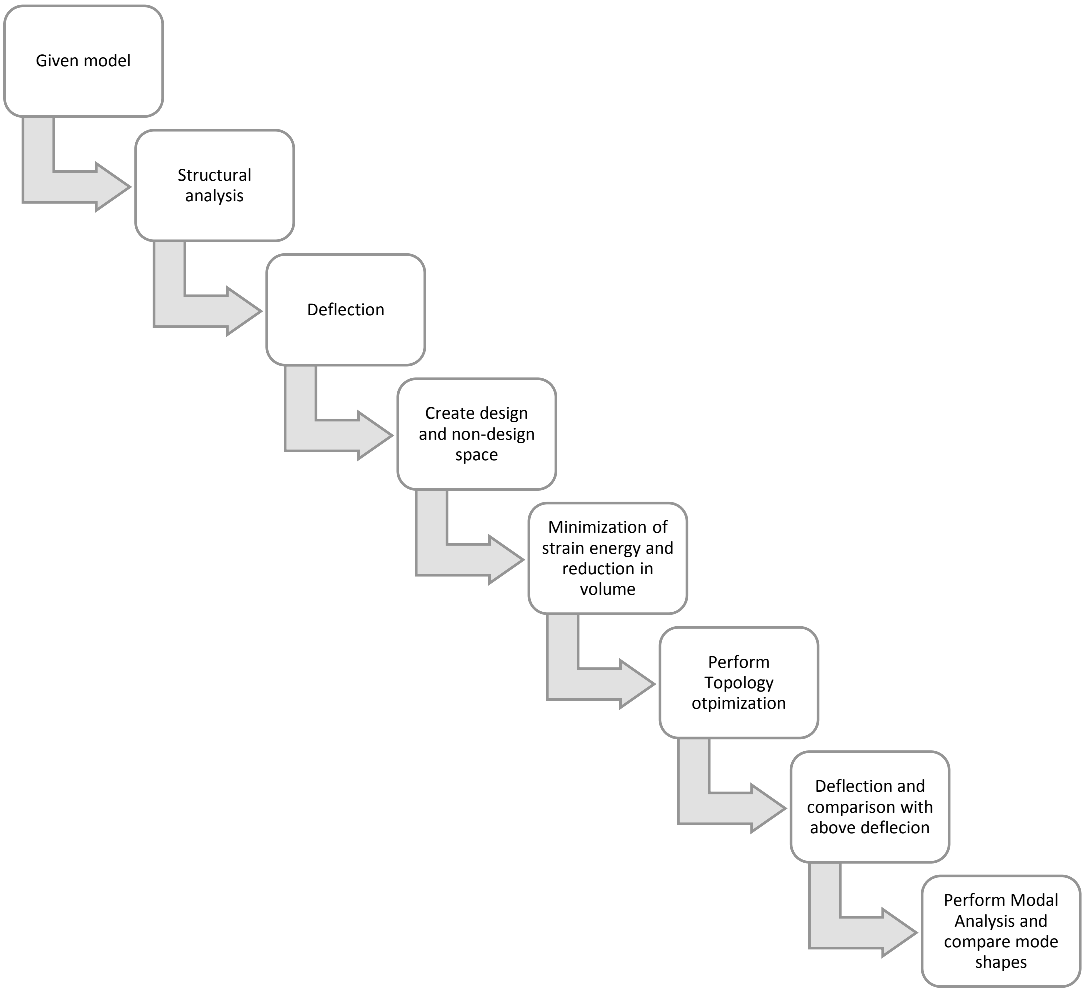

Figure 1: Algorithm:

Solution

Assembly and material properties:

The given model is imported into ABAQUS. The essential parts, that is, tool and the cutting part are assembled (Fig 2). High speed stainless steel (HSS) is assigned for the parts since HSS is used for premium cutting tools.

Material properties of HSS:

Density = 7.90 g/cc

Young's Modulus = 226 GPa

Contact surfaces:

Two surfaces are created, one for tool and the other for cutting part where there is contact between two parts. Now, constraints are given as surface to surface contact between the created two surfaces.

Figure 2: Assembly of tool and cutting part

Meshing:

Tetrahedral elements are used for meshing the two parts.

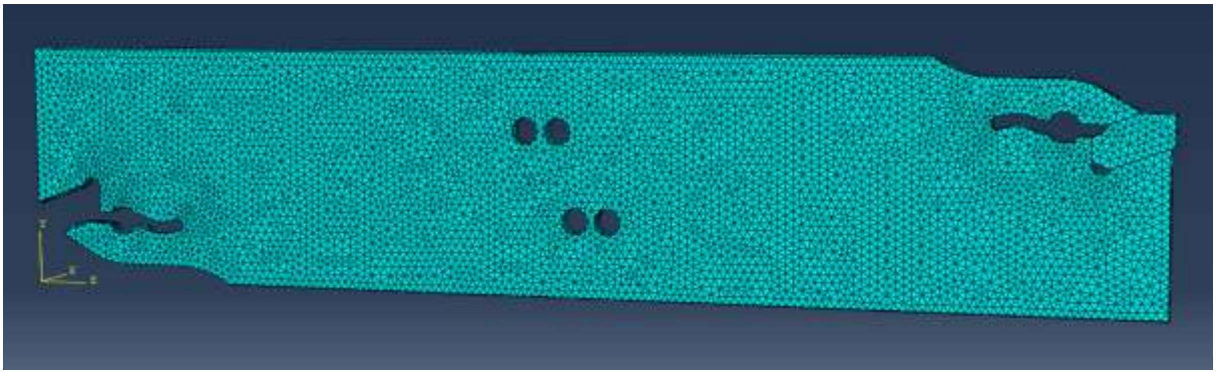

Figure 3: Mesh

Loads and Boundary conditions:

The upper and lower surfaces of the tool are fixed translationally and rotationally in all the directions since that is clamped. A pressure of 100 Pa is applied on the cutting surfaces of the cutting tool.

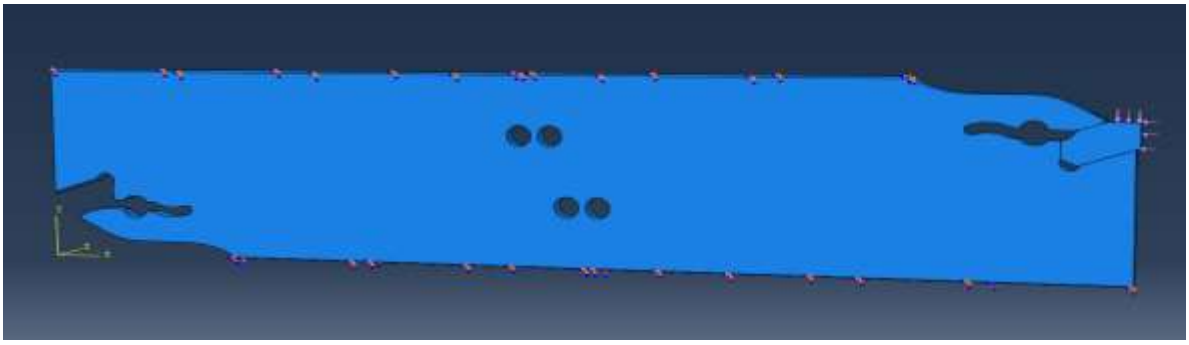

Figure 4: Loads and boundary conditions

Results:

The maximum displacement of the tool is 6.016×10^{-9} m.

Figure 5: Displacement of the tool

<u>New designs</u>: Four new designs are generated with the initial guess design space and further improvement of the design based on the results. For the first two designs, cad model 1 (It's learning) is used and for the next two designs, cad model 2 is used.

Design 1:

(i) The design space is given, partitioning the whole tool leaving the edges and complex areas (figure 5).

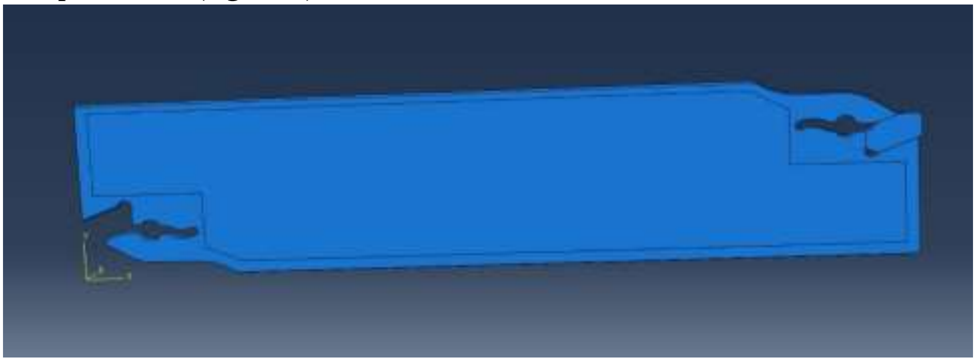

Figure 6: Design 1

(ii) A job is created in the optimization module with the following objective and constraint and is submitted for topology optimization of the design space.
Objective: Minimization of strain energy which helps in increasing the stiffness.
Constraint: Reduction in volume of the tool by 50%.

(iii) It was observed that the whole material from the design space was removed and the maximum deflection was observed to be 6.677×10^{-9} m.

Figure 7: Optimized design 1

Design 2:

(i) Since the deflection in the optimized design 1 is slightly increased, the previous design is improvised by sketching a circle and two cross link rods (figure 8).

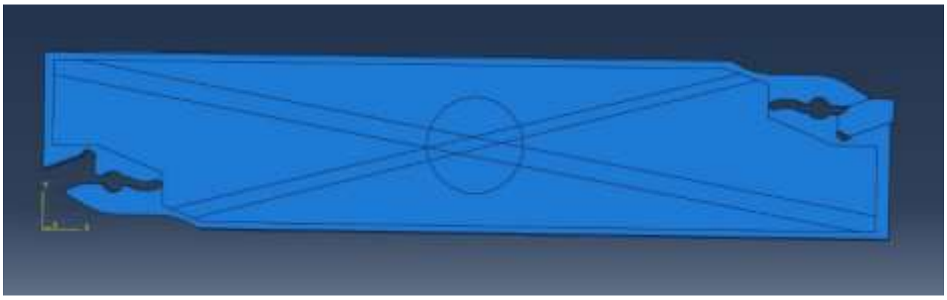

Figure 8: Design 2

(ii) For the same objective function and constraint, the problem is solved.

(iii) It was observed that the maximum deflection was much higher when compared to the above models which is 21.6 m (figure 9). This implies the new design did not worked well in terms of stiffness of the tool.

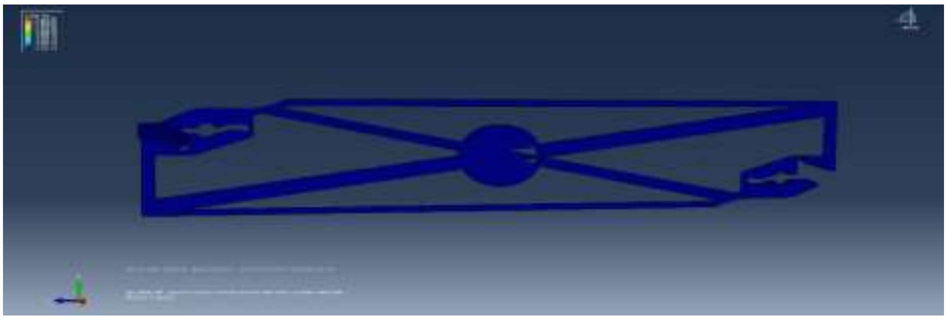

Figure 9: Optimized design 2

Design 3:

(i) Since the above design failed, a new design is tried out with cad model 2.

(ii) The design space is created leaving the right lower space of the cutting tool (because that was not removed when the whole tool was given as design space in Design model 1) and the middle part containing the holes.

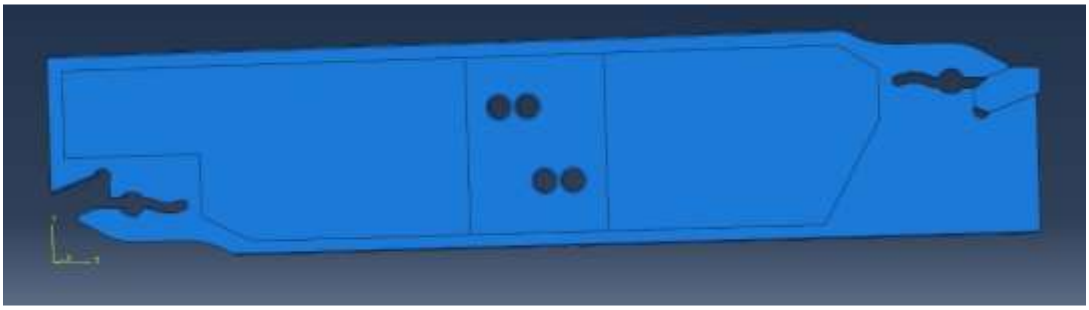

Figure 10: Design 3

(iii) The problem is solved for the same objective function and constraint and the following result is obtained. It was observed that the material of the complete design space is removed leaving a small portion in the right part. The maximum displacement in this case is 6.5×10^{-9} m.

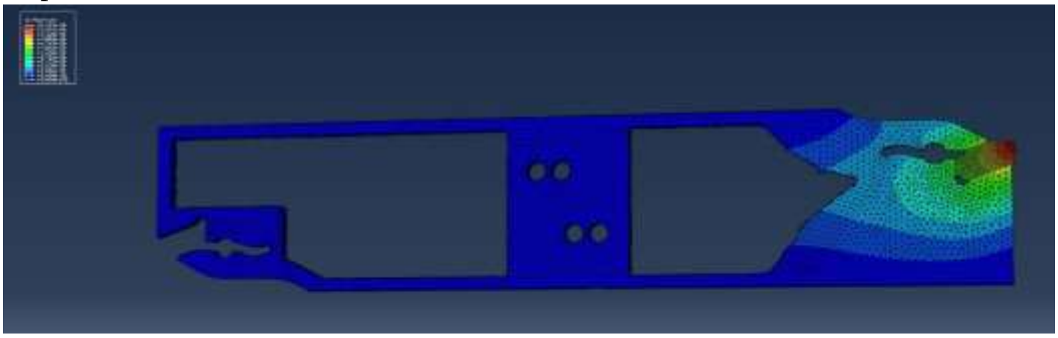

Figure 11: Optimized design 3

(iv) The results seems good compared to the other models.

Design 4:

(i) The above design is improvised by adding link rods to the left and right portions of the design space for the better rigidity of the tool.

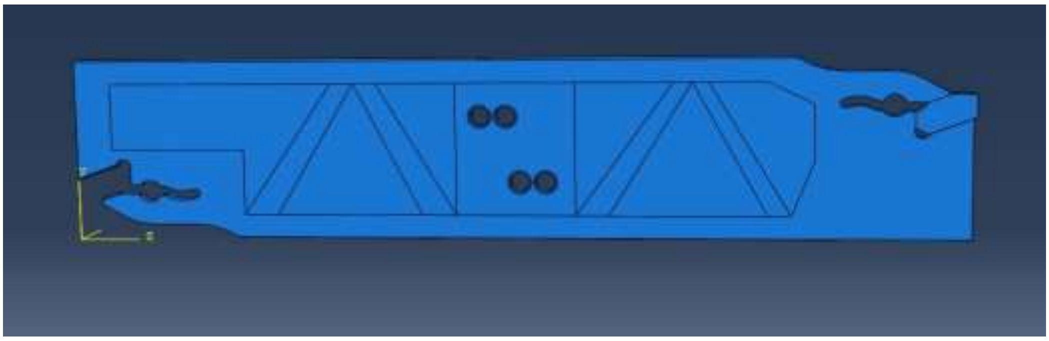

Figure 12: Design 4

(ii) But the results appeared to be similar to that of the design 3

Figure 13: Optimized design 4

Static and Dynamic stiffness:

For the given load and boundary conditions for all the designs, load versus displacement graph is plotted to observe the variations in static and dynamic stiffness.

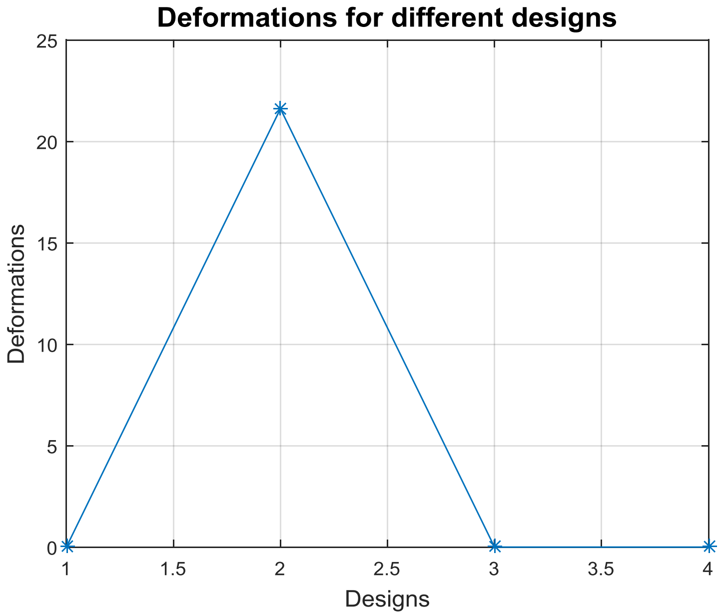

Figure 14: Deformations for different designs

In the above figure, the maximum displacement of each design is plotted on Y-axis and the four designs are plotted on X-axis. It can be observed that the deformation increased from first to second and then it is decreased to third and fourth designs implying that the static stiffness changed for design 2 but not for the other designs.

Now based on the maximum deflections of each design, the dynamic stiffness for a given rotative speed of the workpiece can be analyzed using the following relation [1].

$$DS = SS - M*\Omega^2 \qquad \rightarrow \text{Equation (1)}$$

Where DS is the dynamic stiffness

SS is the static stiffness

M is the mass of the part

Ω is the rotative speed of the workpiece

Let Ω^2=k (constant) and DS_d, DS_1, DS_2, DS_3 and DS_4 be the dynamic stiffness of the given design, design 1, 2, 3 and 4 respectively.

For the generated designs, the volume is reduced by 50% implying the mass also reduced by 50%.

Substituting the values of static stiffness, mass of given model as ‘m’ and the masses of new designs as m/2 in the equation (1), we get the following equations.

$$2DS_1 - DS_d = 1.3332\times10^{10}$$

$$2DS_2 - DS_d = -1.6622\times10^{10}$$

$$2DS_3 - DS_d = 1.4076\times10^{10}$$

$$2DS_4 - DS_d = 1.4076\times10^{10}$$

From the above equations, it can be observed that the difference between twice the dynamic stiffness of the new design and the dynamic stiffness of the given model is positive for designs 1, 3 and 4 and negative for design 2. That implies that the dynamic stiffness increased in designs 1, 3 and 4 and decreased in design 2.

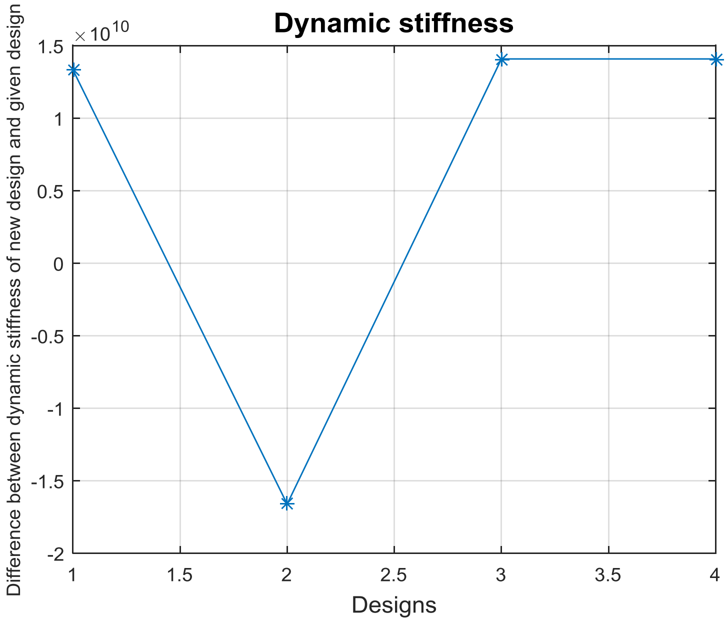

Figure 15: Dynamic stiffness

Hence, design 1, 3 or 4 can be considered. But the deflections of design 3 and 4 are less than that of design 1.

Modal Analysis

Now the modal analysis is carried out for the given tool and the optimized design 4 with five modes. It was observed that the first torsional mode occur for the given and optimized design occurred at the end of the tool but not at the cutting edge. The following are the five modes obtained for the given model and the optimized design 4.

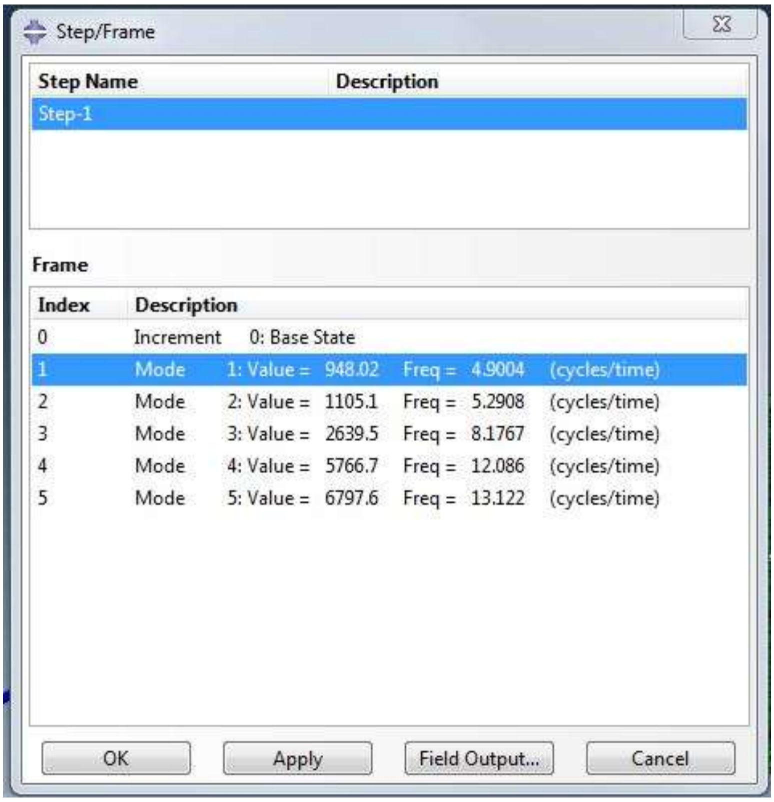

Figure 16: Modal analysis for the given tool

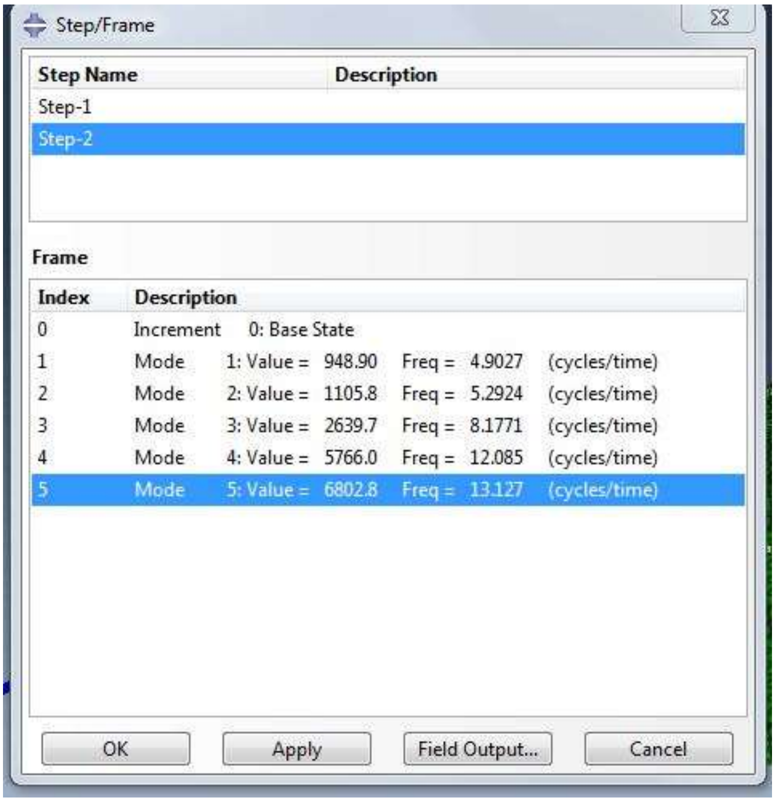

Figure 17: Modal analysis for the optimized design 4

Also from [2], it can be stated that the dynamic stiffness can be increased by shifting the lowest resonance frequency as high as possible. From the figures 16 and 17, it can be observed that the there is a slight increase in lowest resonance frequency.

Influence of tool overhang

The contribution of tool overhang is most important in parting off tool. The parting off tool should be highly rigid which implies it should have very less overhanging length. The more the overhang of the tool, the less rigid it becomes resulting in lesser stiff tool. The overhang of the tool also infers the vibrations of the tool. So the tool should have less overhanging length to minimize its vibrations.

In some cases an inverted tool is used for a robust design. The inverted parting off tool has many advantages.

1. The pull of the tool towards the workpiece is reduced when the tool is inverted.
2. The chip coming off the workpiece tend to fall down directly instead of creating a pile on the top of the cutting edge.
3. Decrease of chip at the cutting edge means clean allowance of coolant at cutting edge.

Discussions and Conclusions

Finally it can be concluded that, the optimized design 4 seems reasonable because of decrease in volume while increase in the dynamic stiffness.

Hence, design 4 is suggested as a better design.

References

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