PERFORMANCE OPTIMIZATION OF CRICKET BAT BY MODIFICATION OF SPINE PROFILE DESIGN

SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENT FOR THE DEGREE OF

BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

SUBMITTED BY

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NOVEMBER 2018

DECLARATION

This is hereby declare that thesis entitled "**Performance Optimization of Cricket Bat by Modification of Spine Profile Design**" is an authentic report of my study carried out as requirement for the award of degree B.Sc. (Mechanical Engineering) at Islamic University of Technology, Gazipur, Dhaka, under the supervision of **PROF. DR. MD. ZAHID HOSSAIN**, Head, Department of Mechanical and Chemical Engineering, IUT during January 2018 to October 2018.

The matter embodied in this thesis has not been submitted in part or full to any other institute for award of any degree.

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CERTIFICATE OF RESEARCH

The thesis titled "**Performance Optimization of Cricket Bat by Modification of Spine Profile Design**" submitted by **Rahman Raad Shahmat** (ID#141411), **Mohammad Saqif Hossain** (ID#141415**), Erfan Wares Khan** (ID#141429**), Muhammad Asif** (ID#141433) has been accepted as satisfactory in partial fulfillment of the requirement for the Degree of Bachelor of Science in Mechanical Engineering on November, 2018.

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ACKNOWLEDGEMENT

We would like to thank Allah (SWT) first of all for giving us the patience, potential and blessings to enable the completion of this thesis, and this would not have been possible without His mercy and generosity.

We would like to thank our supervisor and Head of Mechanical and Chemical Engineering Department, **Prof. Dr. Md. Zahid Hossain** for his guidance, enthusiasm and unwavering willingness to spend his time and wisdom for the care of his students that is truly inspiring. We are extremely grateful to have been privy to his sincere advices and earnest support.

We also express our gratefulness to all the faculty of the department for providing supports that were truly necessary. I would especially like to thank Zibon Mahmud Hasan and Mohammed Intishar Nur for providing us access to the case studies which proved integral for the completion of this thesis.

We would like to thank our parents for the pivotal part they played in allowing us to grow up in a household filled with affection, respect, religious sentiment and grave importance on moral values, all of which allowed me come this far in life.

We are highly indebted to the above-mentioned people and without their encouragement, it would have been impossible to complete this dissertation.

Although we have given our best to complete this thesis flawlessly, we sincerely apologize for any mistakes that may have been made.

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Abstract

The rear spine of a cricket bat gives it a characteristic cross section structure. The sweet spot indicates the position on the bat where the deformation from impact is minimal, and from where the ball comes out with maximum velocity after rebound. By modifying the spine profile structure, the Sweet spot can be improved by increasing the stroke (decreasing the minimum deformation) and enhance the bat performance.

The aim of this study was to design a new modified bat with an improved spine profile, and to compare it with the existing bats. As per the new international regulations that came into effect from September 28, 2017, the design of the bat was done without violating the rules set by ICC. The performance analysis and comparison of the bats were executed through simulation, using finite element modeling followed by modal analysis to determine the regions and magnitude of vibrational deformation using ANSYS Workbench.

Chapter 1

Introduction

Cricket as a sport has gained much popularity in half of the world. People enjoys the game by playing it and watching it. The charm of the game is kept by governing the game with some codes of law for over 250 years. Alterations and additions to these codes have been made by the recommendations of the governing authorities of the time.

The Cricket Bat is the most significant equipment for the game of cricket along with the cricket ball. The game of cricket involves the action of hitting a ball made of cork and leather, delivered by a bowler using the cricket bat. A generic cricket bat is made of a blade of Willow wood, joined with a handle made of cane.

The 'sweet spot' is one of the most important cricket bat parameters. It is located at the bat's front face of the blade, primarily identified by the batsman as the best preferred location where the batsman aims the ball to strike. When a ball hits this sweet spot, it attains the maximum exit velocity and covers the maximum distance. [1] The batsman also feels minimum jarring on his hands and forearms when the ball strikes on the bat's sweet spot. [2] The sweet spot, as defined by Cross on the study of his baseball bat and racquet is an impact point on the bat where the force transmitted to hand by the ball's impact is felt the least. [3]

To improve the stroke of a cricket bat, several modifications have been done on its overall structure and materials used to make the cricket bat. Thus, some of those attempts caused the ICC (International Cricket Council) to come up with new regulations on bat dimensions and material for fair play.

1.1 Background and Present State

The first cricket bat design were laid on 1788. Since then the design has evolved throughout the ages by different modifications to provide an edge in favor for either the batsman or the bowler. However, it was since era of Sir Donald George Bradman, that the implementation and development of the cricket bat design was looked upon with great interest. Some designs were suggested made of materials other than wood but the results were not up to the mark. In 1979, Dennis Lillie used a bat made of aluminum, named 'the ComBat' which after a few overs began damaging the ball, as claimed by the opposing English captain. This bat was replaced by its orthodox wooden counterpart and a new rule was set that the bat must be made of wood. The blade was to be made of willow wood which is strong, lightweight and has good shock resistance. The handle was to be made of cane, which has good shock absorbing properties. The length of the bat cannot exceed 38 inches (96.5 cm), and the width of the blade must be less than 4.25 inches (10.8 cm). From, September 28, 2017 ICC implemented the rule that the thickness of the edge can be no more than 40mm, and the thickness of the bat must not exceed 67mm at any point. Within this limitation, the batsman should choose his bat.

1.2 Functional Requirements

1.2.1 Design

Design refers to a plan or drawing or a decorative pattern produced to show the look and function or workings of an object before it is made. It is the creation of a plan or convention for the construction of an object, system or measurable human interaction. Design has different connotations in different fields. In some cases, the direct construction of an object is also considered to use design thinking.

Generally the construction of a Cricket bat consists different types of parts. The blade of a cricket bat is a wooden block that is generally flat on the striking face and with a ridge on the reverse (back) which concentrates wood in the middle where the ball is generally hit. The blade is connected to a long cylindrical handle, similar to that of a mid-20th-century tennis racquet, by means of a splice. A blade of modern bat has varying degree of curves, usually known as bow of the bat. Selection of bat with different degree of bow is a personal choice, as each curve has its own advantages.

Figure 1.1: Parts of a cricket bat

The handle is usually covered with a rubber grip. Bats incorporate a wooden spring design where the handle meets the blade. The current design of a handle spliced into a blade through a tapered splice was the invention in the 1880s of Charles Richardson, a pupil of Brunel and the first Chief Engineer of the Severn Railway Tunnel. Spliced handles had been used before this but tended to break at the corner of the join. The taper provides a more gradual transfer of load from the bat's blade to the handle and avoids this problem.

The edges of the blade closest to the handle are known as the shoulders of the bat, and the bottom of the blade is known as the toe of the bat.

The profile of the back of the blade is significant in getting the right pick-up and balance. Spine of the bat is the line in the center of the bat running down from the shoulders of the blade to its toe.

The swell of the bat also known as sweet spot or middle of the bat, is the area where a batsman would usually want to make a contact with ball. As more wood is behind the blade at the sweet spot, more impact it will have on ball when hit. The two important characteristics of swell that have significant importance are its position and depth.

Bats were not always this shape. Before the 18th century bats tended to be shaped similarly to a modern hockey sticks. This may well have been a legacy of the game's reputed origins. The bat generally recognized as the oldest bat still in existence is dated 1729 and is on display in the Sandham Room at The Oval in London.

1.2.2 Size

The preferable size of a traditional cricket bat depends solely upon the preference and comfort of the batsman using it, exclusive to his/her height, strength, playing style and game format.

Bat Size	Approx. age	Batsman's Height	Bat Length	Bat Width
1	4-5	4' - 4' 3"	25 ¼"	3 ½"
2	6-7	4' 3" - 4' 6"	27 3/4"	3 ½"
3	8	4' 6 " - 4' 9"	28 3/4"	3 ¾"
4	9-11	4' 9 " - 4' 11"	29 3/4"	3 ¾"
5	10-12	4' 11 " - 5' 2"	30 3/4"	4"
6	11-13	5' 2" - 5' 6"	31 3/4"	4"
Harrow	12-14	5' 6" - 5' 9"	32 3/4"	4 1/6"
Short Handle (SH)	15+	5' 9" - 6' 2"	33 1/2"	4 ¼"
Long Handle (LH)	15+	6' +	34 3/8"	4 ¼"

Table 1.1 : Size chart of cricket bat according to age and player height

As shown in the Table 1.1 , the bat sizes can range to a great variety according to player body parameters. But there is no obligation for the bat size to choose.

1.2.3 Material

The traditional cricket bat is composed of two parts – Handle and Blade – joined together by adhesive, spliced into the blade through a tapered splice. The blade and the handle is made with different materials. The blade is generally made with English willow wood – *a linear elastic orthotropic material* – and the handle is made with Cane – *a linear elastic orthotropic material*.

This variance of material of the blade and handle are because of having advantages of the different structural properties required for the specific regions of the bat.

English willow wood provides the required strength and rigidity to the blade, while keeping the overall weight of the bat low, aimed to have a great impact on the cricket ball during collision. Whereas the Cane in the handle helps to dampen the impact vibration during playing a shot and contributes to the durability of the bat.

The following table illustrates the physical properties of the materials:

Material	**Density (kg/m^3)**	**Young's Modulus (GPa)**			**Poisson's Ratio**			**Shear Modulus (GPa)**		
		E_x	E_y	E_z	v_{xy}	v_{yz}	v_{yz}	G_{xy}	G_{yz}	G_{zx}
English Willow wood	535	13.3	0.883	7.08	0.32	0.28	0.28	1.33	0.133	1.33
Cane	550		5			0.3				

Table 1.2: Physical properties of English willow wood and Cane

All bats have different characteristics from balance and pick up to the width of the grain. As a rule of thumb, the softer (narrow grain) willow has excellent performance qualities but shorter lifespan, whereas the harder (broader grain) willow tends to last longer but takes time before you get optimum performance from it. A good compromise between the two would be a blade with about 8-12 grains. This guidance on grading hopefully helps players in making an informed judgment when selecting a bat and of course looking after it properly in use. English Willow can be of mainly 5 grades-

A Grade LE (Limited Edition) is the best looking and performing blade money can buy and is in the top 4% of willow. The grain on the face will be straight and there will be at least 10 grains visible. These are an incredibly good piece of willow turned into the finest bat imaginable. The price of one of these bats would be over £350 for a full sized blade and over £150 for a junior blade.

GRADE LE

A Grade 1 is the best looking blade money can buy, though it will not necessarily play the best. There may be some red wood evident on the edge of the bat. The grain on the face will be straight and there will be at least 4 grains visible. There may be the odd small knot in the edge or back but the playing area should be clean. The price of one of these bats would be between £250 and £300 for a full sized blade and £120-£150 for a junior blade.

GRADE 1

A Grade 2 is also very good quality and normally a larger amount of red wood can be seen on the edge of a bat, this has no effect on the playing ability of the bat it is purely cosmetic. Again there will be at least 4 straight grains on the face of the bat with maybe some blemishes, pin knots or "speck" visible. The price of one of these bats would be between £200 and £250 for a full sized blade and around £100-£120 for a junior blade.

GRADE 2

This grade offers very good value for money. A Grade 3 Blade has up to half colour across the bat, again this has no direct relation to the playing ability of the wood, it just has less visual attraction. There will be a minimum of 4 grains on the face of the bat which may not always be perfectly straight. Again some small knots or a little 'butterfly' stain may be present with perhaps more prominent "speck". The price of one of these bats would be between £100 and £150 for a full sized blade and £50-£75 for a junior blade.

GRADE 3

Kashmir willow found in cricket sets and sub £45 junior bats. Kashmir willow is harder and dryer by nature than English willow, so doesn't perform as well or last as long. This bat is ideal as a starter bat for use against a softer safety ball (Incrediballs, Wonderballs, Windballs e.t.c)

1.2.4 Cost

In the sports equipment market, the cricket bats come in a well spread range of prices. This is mainly because of the variance of build quality and branding preferences. English willow wood is a very rare material to procure in the global market, and which is why internationally the scarcity and the demand of the material has caused its price to increase.

This is why, alternate materials have been adopted globally having significantly close physical properties to English willow, such as Kashmir willow and Kerosene wood.

Another aspect having an impact upon the price is the craftsmanship for manufacturing cricket bats. Even with the availability of sophisticated technologies, the cricket bat manufacturing requires fine craftsmanship from skilled labor.

1.3 Spine and Spine Profile

The profile of the back of the blade is significant in getting the right pick-up and balance. Spine of the bat is the line in the center of the bat running down from the shoulders of the blade to its toe. Profiles of back of the bat are designed by scooping out wood on either side of the spine. More the wood is taken out of the bat, more the profile becomes concaved shape and makes the spine sharper.

Modern bats usually have more concaved shaped profile as compared to classic bats, which helps reducing the weight of the bat and at the same time maintaining the depth of the swell and thickness of the edges.

Cricket bats which have more concave profiles have less wood towards the edges. This makes the bat more prone to turn when a ball hits the bat towards the edges and not in the center, as less wood is behind the ball. Hence, some amount of energy is lost in the turning motion and full power is not transferred to the ball. [12]

Figure 1.2: Different spine profiles

- A full shape allows off centre strikes to be more powerful but it isn't possible with the maximum edge size in lighter weights.
- A full shape allows off centre strikes to be more powerful but it isn't possible with the maximum edge size in lighter weights.
- A concaved shape allows a maximum spine and maximum edge at a light weight. Off centre strikes aren't as powerful as a full shape.

1.4 Stroke

Imagine a cricket ball sailing through the air at around 145 km/h (90 mph). A batsman stands ready, bat in hand. In the brief moment before the ball arrives, the player is most likely thinking of how to best hit a shot. There are many ways for the cricket ball to connect with the bat, but if a batsman knows the location of a sweet spot, he or she may be able to deliver a better shot by taking advantage of an optimal zone that enables maximum stroke power with the least amount of effort. The ability of the sweet spot of hitting a ball is known as stroke of the bat.

1.5 Sweet Spot

Sweet spot is a location primarily identified by the batsman as the best location on the bat with which the ball can come in contact. The sweet spot or middle of the bat is the area of the blade where you achieve the largest amount of power in the shot you are playing. The middle is usually dictated by the profile through the back of the bat.

The sweet spot has three physical interpretations.They are-

- It produces maximum batted ball velocity.
- It produces minimum deformation on handle.
- It produces minimum amplitude of vibration.

Sweet spot is the point of the bat where the edge thickness is highest. While the bat vibrates on its natural frequency, lowest deformation zone is created around the sweet spot.

Most players will have a bat with the normal sweet spot. This would be about 4” to 12” from the toe. A bat with a normal sweet spot will suit a batsman who plays the full range of shots. This sweet spot does not favor any style in particular. According to the position of the sweet spot a cricket bat can be of three types –

1. High Position Sweet Spot : sweet spot 250mm above from bottom
2. Medium position sweet spot : sweet spot 225mm above from bottom
3. Low position sweet spot : sweet spot 210 mm above from bottom

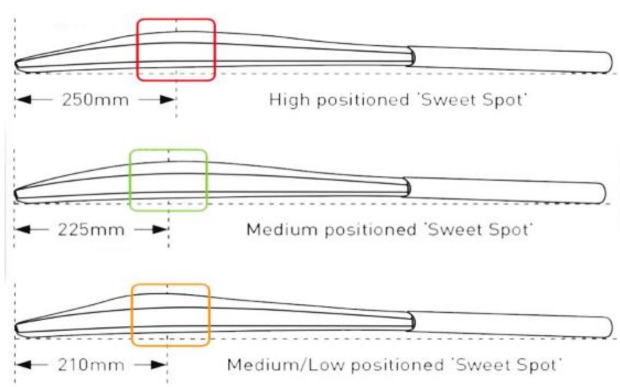

Figure 1.3: Different sweet spot locations

1.6 Maintenance & Knocking

Most Cricket bats are made from Salix Caerulea or Alba Var English willow, which is by nature a soft fibrous timber which possesses the perfect characteristics, namely balance, power and durability to perform in a Cricketing environment. The qualities of English willow are enhanced during production through the drying and pressing of the timber.

All Cricket bats will sustain wear and tear during use, this is perfectly natural, and with collision speeds over 100 mph, it is easy to see why. Normal wear and tear expected from a cricket bat blade is surface cracking to the face and edges and discoloration of the blade, and in these cases the performance of the bat won't be affected. Damage on the other hand can occur due to misuse, mistimed strokes, incorrect storage, and lack of maintenance, use against substandard cricket balls and use in wet conditions. If damage appears on the bat, it should be referred immediately for a repair.

To make sure that you gain the most from your new Cricket bat it is essential that it is prepared (knocked in) and maintained in the correct manner. Once the bat has been knocked in it is imperative that you should maintain your bat as follows-

- Store in a moderate constant temperature.
- Try to avoid wet conditions.
- Try to avoid use against cheap substandard balls.
- Try not to drive Yorkers.
- **Don't over oil the bat.**
- Try to avoid excessive mistimed shots.

A strong recommendation is that bats should be booked in for end of season work. This can include all levels of repair, oiling, re-gripping, toe guard fitting and anti-scuff sheet fitting, and is proven that it will help prolong the life of your bat.

1.7 Literature Review

Numerous research has been performed till now upon the enhancement of performance of sports equipment such as cricket bats, baseball bats, tennis racquets, balls, etc. In 2014 a research was done by David Curtis, Georgina Hurt and Ben Heller which attempted to relate tapping test (which is a qualitative test where the performance and longevity of the bat is assessed by experienced players through sounds that the bat makes when a ball is dropped on it) with the bat's actual performance as indicated by Apparent Coefficient of Restitution (ACoR). They collected tapping test data by surveying experienced cricketers, and measured the bat's ACoR using standard equipment [4]. In another research, Ajay K. Sarkar, Daniel A. James, Andrew W. Busch and David V. Thiel devised a method to predict sweet spot hits using accelerometers fitted into the batsman's wrists, using the fact that a sweet spot impact will generate the minimum of vibration in the player's wrists [5]. A research paper titled "Dynamic Analysis of Impact of Ball on Cricket Bat and Force Transfer to The Elbow" by Aayush Kant, P.M. Padole and Rashmi Uddanwadikar, describes a research on the relation of exit velocity of ball with impact position on the bat, and finite element modelling was used [6]. A research by David James, David Curtis, Tom Allen and Tom Rippin compared performance of three different bats and the data obtained compared with predictions generated using rigid body modelling [7]. Another research compared different types of bowling deliveries on batsmen fitted with motion sensors [8]. A research was performed where detailed multi-layered and multi-material Finite Element Modeling was applied to a Kookaburra Ball and used to predict outcomes of drop tests and high speed impact tests. There were good agreement between the predictions and experimental results [9]. Another research conducted by Tom Allen, Olivier Fauteux-Brault, David James and David Curtis used Finite Element modeling of a cricket bat/ball impact. The models were verified using separate impact tests. FE models were produced for two bat geometries, each modelled as a rigid body, and compared to experimental data obtained from impact tests [10]. Researches were also done on different batting styles, like the one on Straight Drive Swing performed by Ajay K. Sarkar and David V. Thiel, where two triaxial accelerometers were mounted on the bat and kinematic analysis done using high speed video camera. The swing motion and bat posture were investigated on this study [11].

1.8 Objective and Aim

The aim of this study is to enhance the performance of cricket bats by analyzing the optimum spine profile design, an implication of which will not only have impact upon its sweet spot, i.e. the region of the bat with minimum impact vibration and hence an ability to produce maximum stroke, but also provide increased comfort for the batsman by reducing the impact on his wrists, within the regulations of international cricket bat standards. This project aims to provide opportunities for further research and development of sports science and engineering. Specialized software packages were being used to model the bat and produce simulations, while a number of experiments to be performed upon the prototype based on the model, using available laboratory equipment to obtain empirical results. The bat is to be compared with a traditional bat as standard, which being modeled in the CAD software maintaining all the dimensions and materials. This proposed modified model is aimed to have increased stroke in the sweet spot (i.e. minimizing the minimum vibrational deformation).

Chapter 2

Design and Methodology

For the analysis of the traditional cricket bat, a CAD model of the cricket bat was created, which was further simulated to map and determine the magnitude and area covered by the region of minimum deformation or the sweet spot.

The work flow of the analysis process can be portrayed as follows-

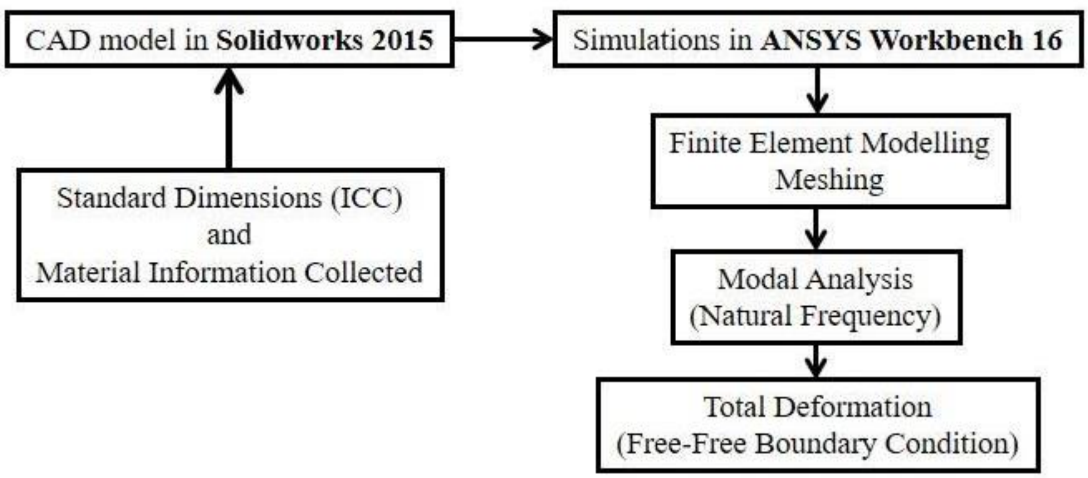

Figure 2.1: Design and Methodology work flow for the traditional bat

2.1 Design

The CAD model of a traditional cricket bat was created in Solidworks 2015. Shape and the dimensions of the bat were very finely scrutinized and kept well under the regulations of ICC as a standard sized cricket bat.

The bat was designed maintaining the following parameters:

- Face Width – 108 mm
- Blade Height – 559 mm
- Edge Thickness – 25 mm
- Neck Fillet Radius – 20 mm

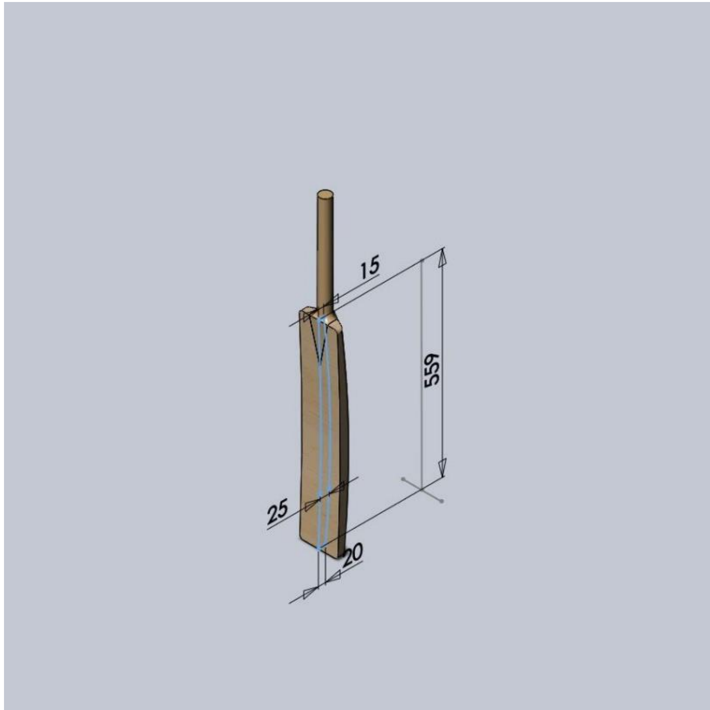

Figure 2.2: Isometric view of the traditional bat CAD model

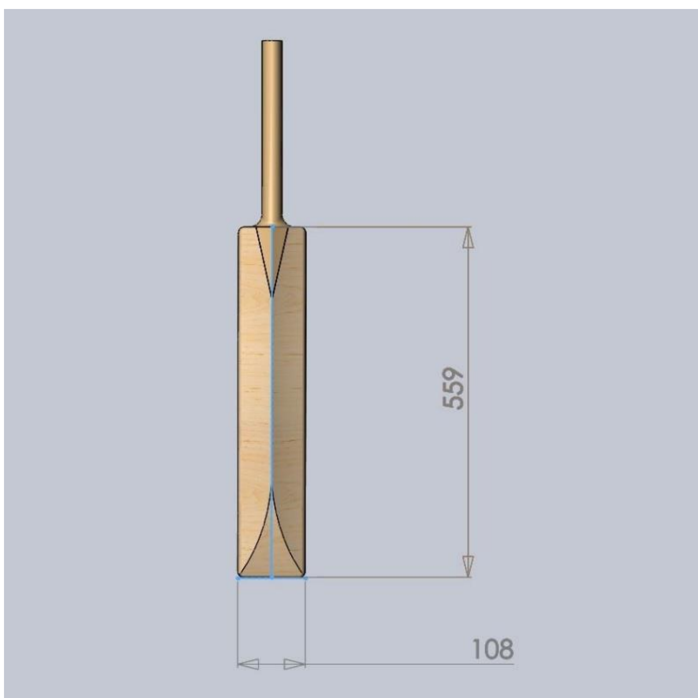

Figure 2.3: Front view of the traditional bat CAD model

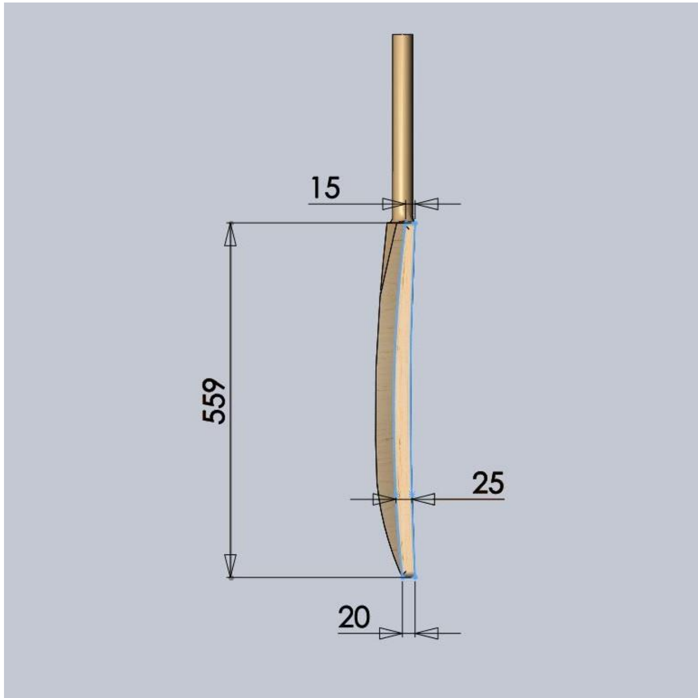

Figure 2.4: Side view of the traditional bat CAD model

2.2 Simulation

The simulations of the model created are performed in ANSYS Workbench 16. At first, the CAD model was loaded in to the workbench and materials were assigned for the individual parts. Then, Finite Element Modeling or Meshing was done. Followed to that, Modal Analysis was performed on the meshed model to determine the Natural Frequency. And finally, the total deformation was calculated and mapped for the meshed model.

2.2.1 Finite Element Modeling

The parts of the model were assigned with each individual materials as per Table 1.2. The handle is assigned to have Cane as material, while the blade is assigned with English willow wood. The physical properties were input to the workbench.

Model (A4) > Geometry	
Object Name	*Geometry*
State	Fully Defined
Definition	
Source	E:\THESIS 2018\IGs\Standard bat.IGS
Type	Iges
Length Unit	Meters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	0.10922 m
Length Y	0.85612 m
Length Z	6.2738e-002 m
Properties	
Volume	2.4117e-003 m^3
Mass	1.2958 kg
Scale Factor Value	1.
Statistics	
Bodies	2
Active Bodies	2
Nodes	38957
Elements	25787
Mesh Metric	None

Figure 2.5: Geometry data of the traditional bat simulation

TABLE 3
Model (A4) > Geometry > Parts

Object Name	*Part 1*	*Part 2*
State	Meshed	
Graphics Properties		
Visible	Yes	
Transparency	1	
Definition		
Suppressed	No	
Stiffness Behavior	Flexible	
Coordinate System	Default Coordinate System	
Reference Temperature	By Environment	
Material		
Assignment	English Wllow Wood	Cane
Nonlinear Effects	Yes	
Thermal Strain Effects	Yes	
Bounding Box		
Length X	0.10922 m	5.2804e-002 m
Length Y	0.56173 m	0.41282 m
Length Z	6.2738e-002 m	5.5214e-002 m
Properties		
Volume	2.0442e-003 m³	3.6749e-004 m³
Mass	1.0937 kg	0.20212 kg
Centroid X	0.21249 m	0.2121 m
Centroid Y	-0.13708 m	0.24138 m
Centroid Z	0.26649 m	0.27026 m
Moment of Inertia Ip1	2.3356e-002 kg·m²	2.6429e-003 kg·m²
Moment of Inertia Ip2	1.0847e-003 kg·m²	3.4906e-005 kg·m²
Moment of Inertia Ip3	2.4087e-002 kg·m²	2.6392e-003 kg·m²
Statistics		
Nodes	24694	14263
Elements	16218	9569
Mesh Metric	None	

Figure 2.6: Geometry data of the parts of traditional bat simulation

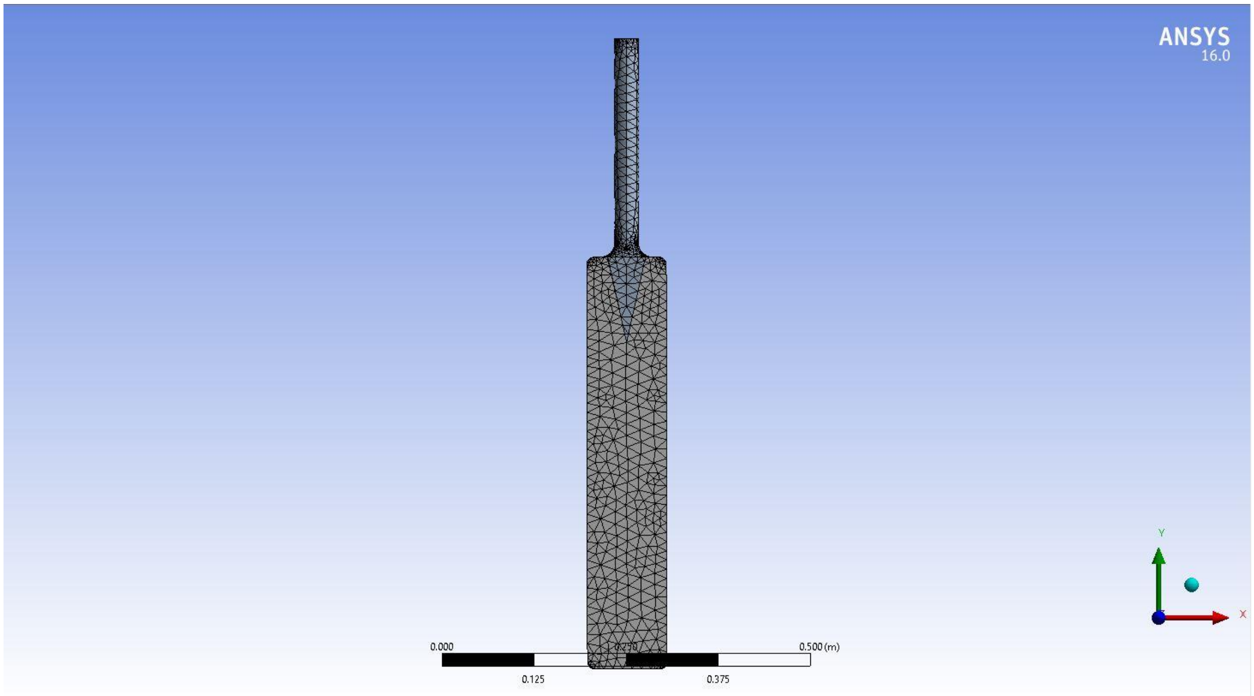

Figure 2.7: Finite Element Modeling (Meshing) of the traditional bat

As according to the figure, the mesh was generated under ‘fine’ meshing to divide the whole assembly into small blocks of solids for the ease of calculations and simulations to be performed.

The generated mesh had 38957 nodes and 25787 elements.
The minimum mesh length was 1.0114e-005 m.

Model (A4) > Mesh	
Object Name	*Mesh*
State	Solved
Display	
Display Style	Body Color
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	High
Transition	Slow
Span Angle Center	Fine
Minimum Edge Length	1.0114e-005 m
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Patch Independent Options	
Topology Checking	No

Figure 2.8: Meshing Data of the traditional bat simulation

2.2.2 Modal Analysis

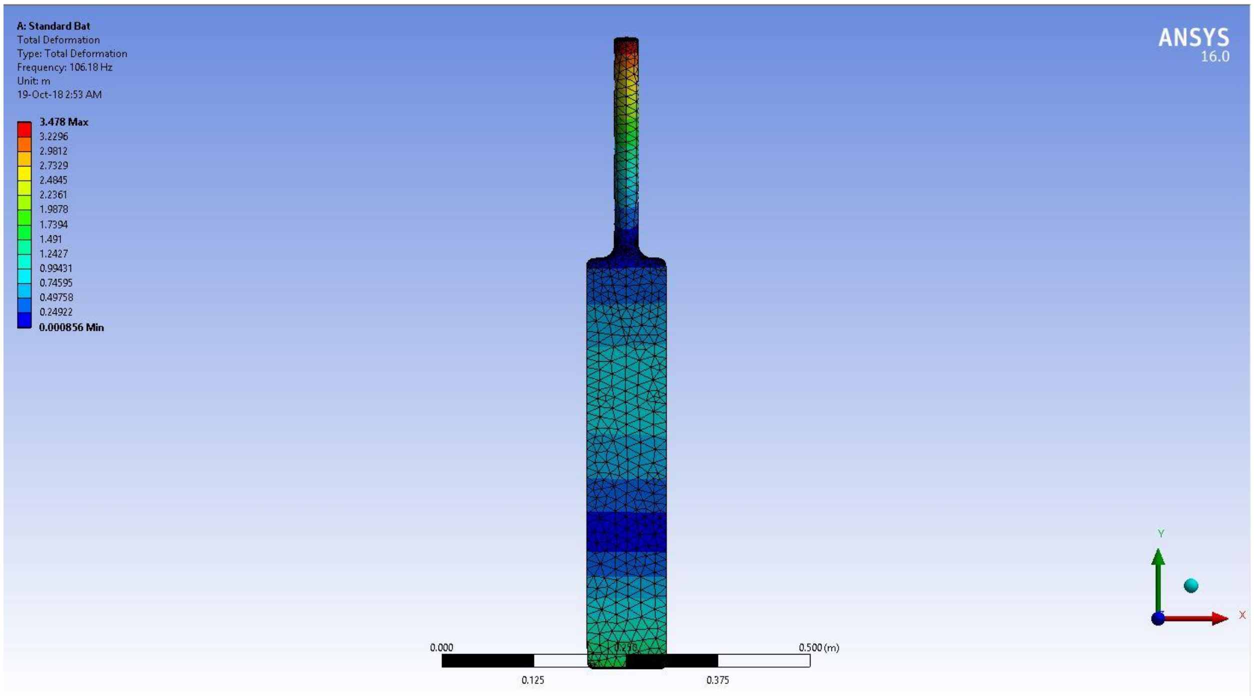

Figure 2.9: Modal Analysis of the traditional cricket bat

Model (A4) > Modal (A5) > Solution (A6)

Mode	Frequency [Hz]
1.	0.
2.	
3.	1.0013e-003
4.	1.2432e-003
5.	0.69045
6.	1.7751
7.	106.18
8.	163.39
9.	255.78
10.	411.05
11.	474.85
12.	645.56
13.	763.98
14.	821.9
15.	1048.9
16.	1107.8
17.	1184.6
18.	1206.8
19.	1366.5
20.	1592.9

Figure 2.10: Frequencies under each modes for Modal Analysis of traditional cricket bat

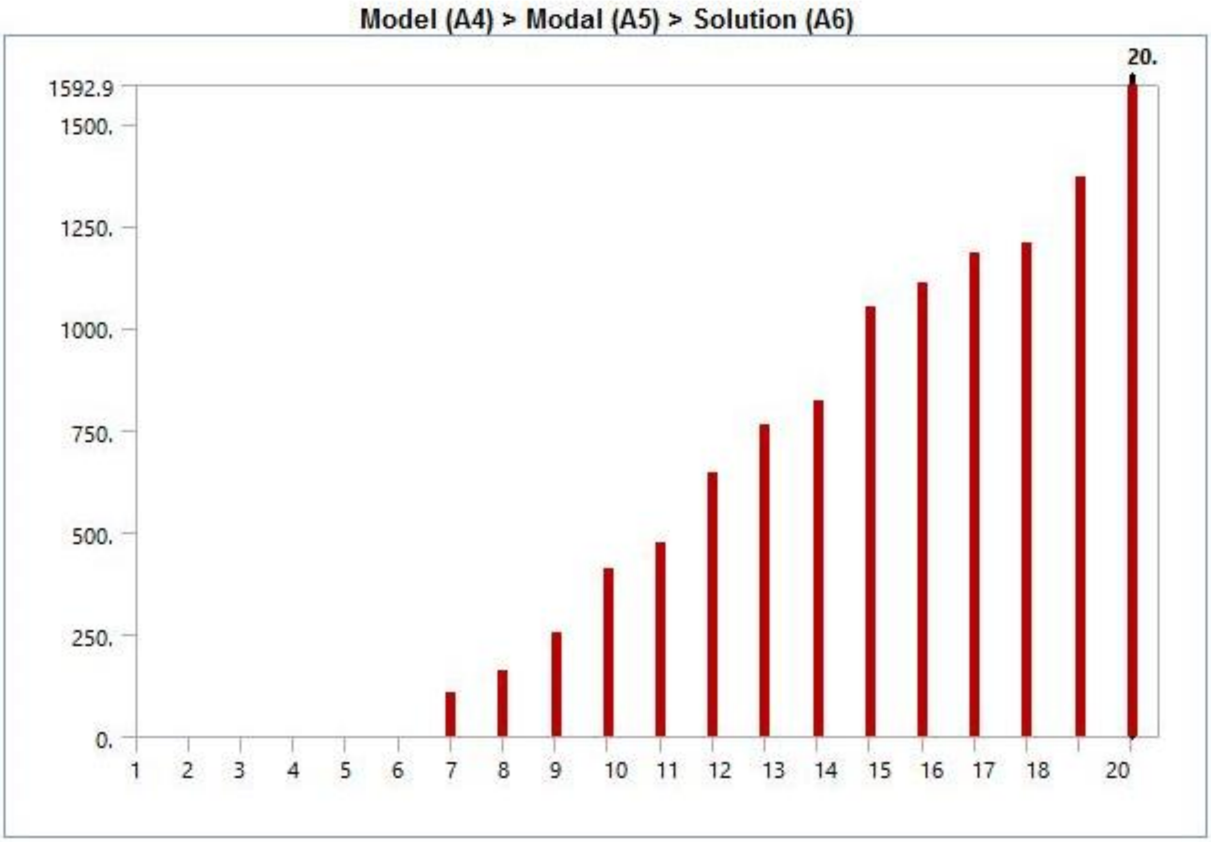

Figure 2.11: Frequency chart of Modal Analysis of the traditional cricket bat

As seen in the figure, 7th mode is selected since it gives the first natural frequency. The dark blue region indicates the minimum deformation of the whole assembly. The frequency of the 7th mode was 106.18 Hz, and the minimum deformation of the dark blue mapped region was 0.000856 m.

Chapter 3

Design Modification and Optimization

In aim to obtain a better performing cricket bat and to study the behavior of the sweet spot and the minimum deformation value with the structural changes, a few structural parameters were chosen. The parameters are –

- Edge
- Thickness
- Face width
- Neck Fillet Radius
- Spine Shape

The standard design was changed either increasing or decreasing only one of the mentioned parameters keeping all the other parameters and dimensions constant. The resulting CAD design was simulated for Modal analysis to study the impact upon the sweet spot area and the minimum deformation. This trial and error process for the structural analysis resulted to filter out the desirable changes that supported the enhancement of the sweet spot, and further these parameters were iterated to propose one optimal design. The structural analysis was performed as per the following method -

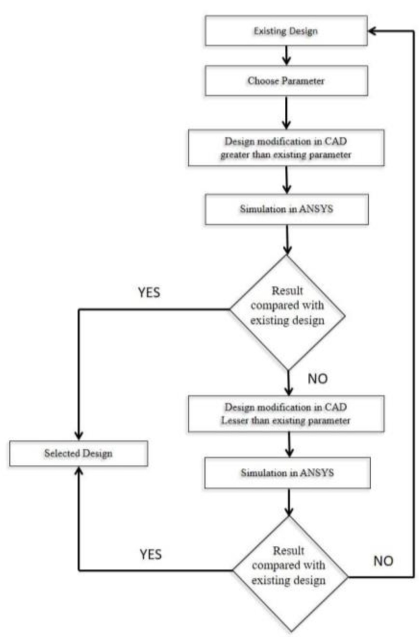

Figure 3.1: Structural Analysis Flow Chart

The simulation results of the trial and error phase are as follows –

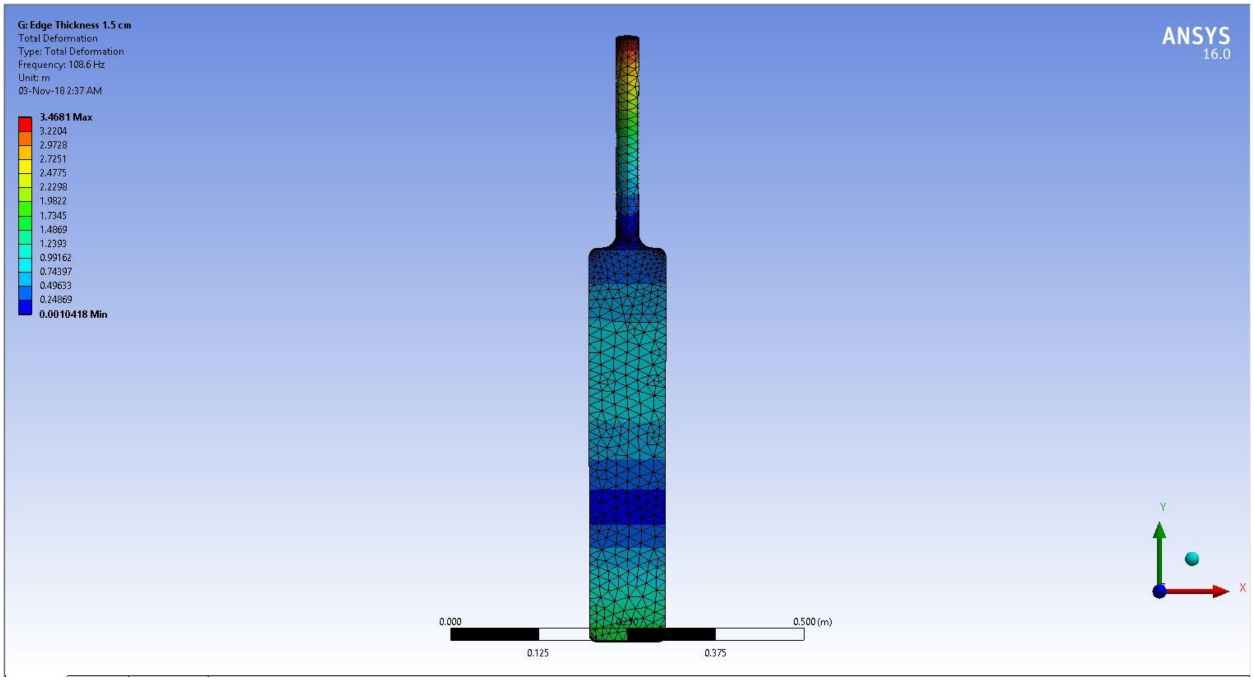

Figure 3.2: Modal Analysis for Edge 15 mm

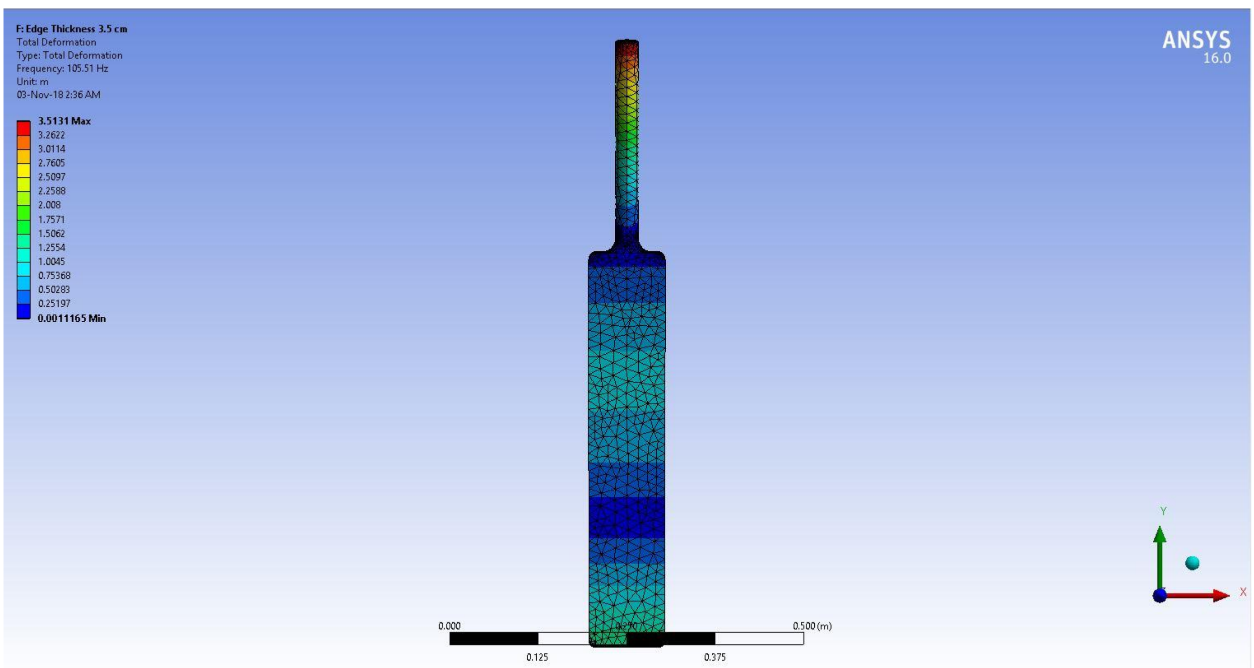

Figure 3.3: Modal Analysis for Edge 35 mm

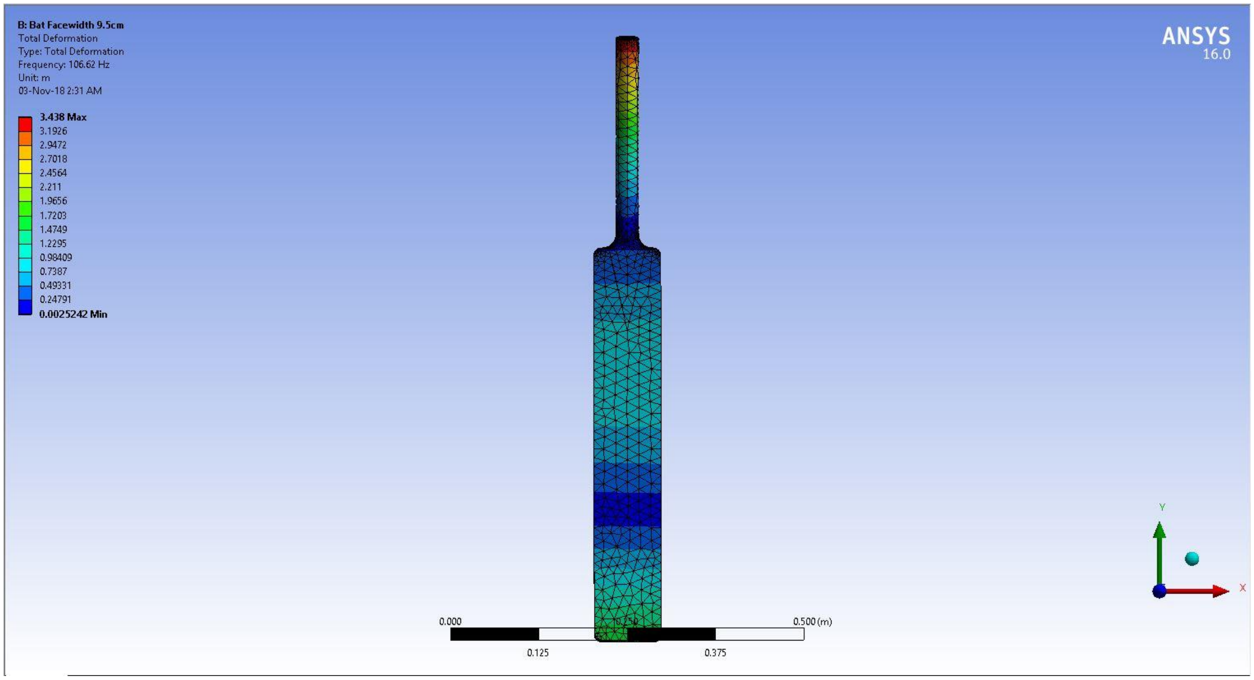

Figure 3.4: Modal Analysis for Face Width 95 mm

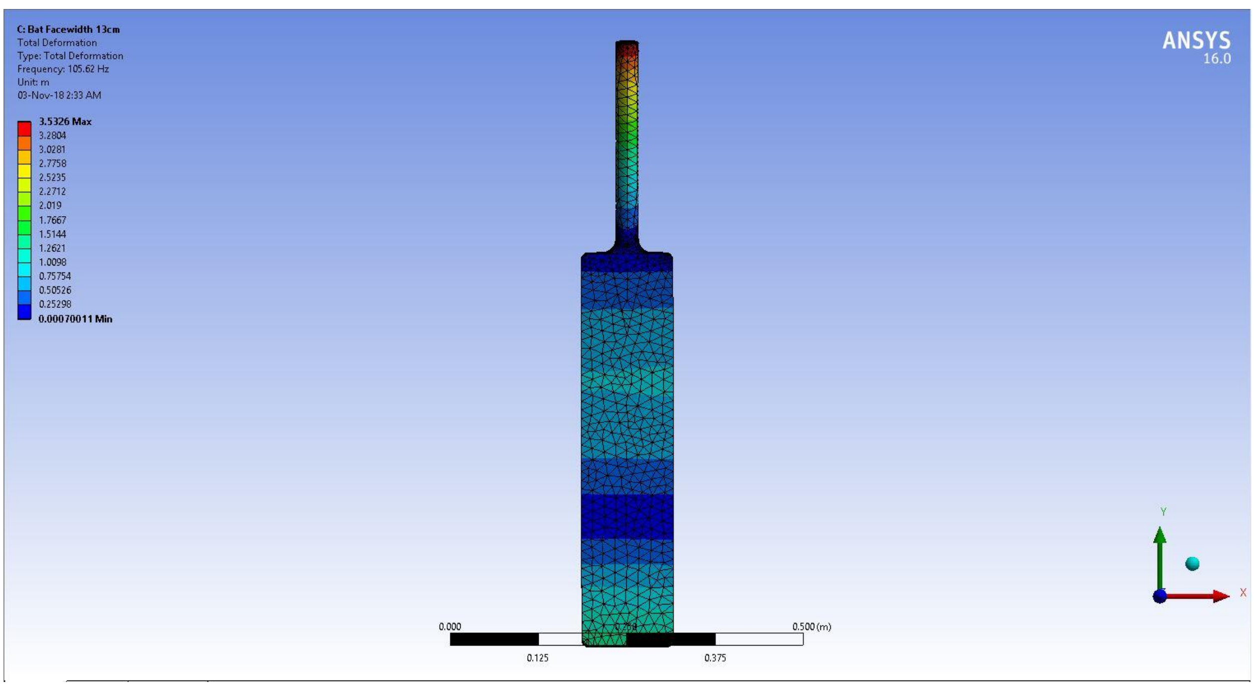

Figure 3.5: Modal Analysis for Face Width 130 mm

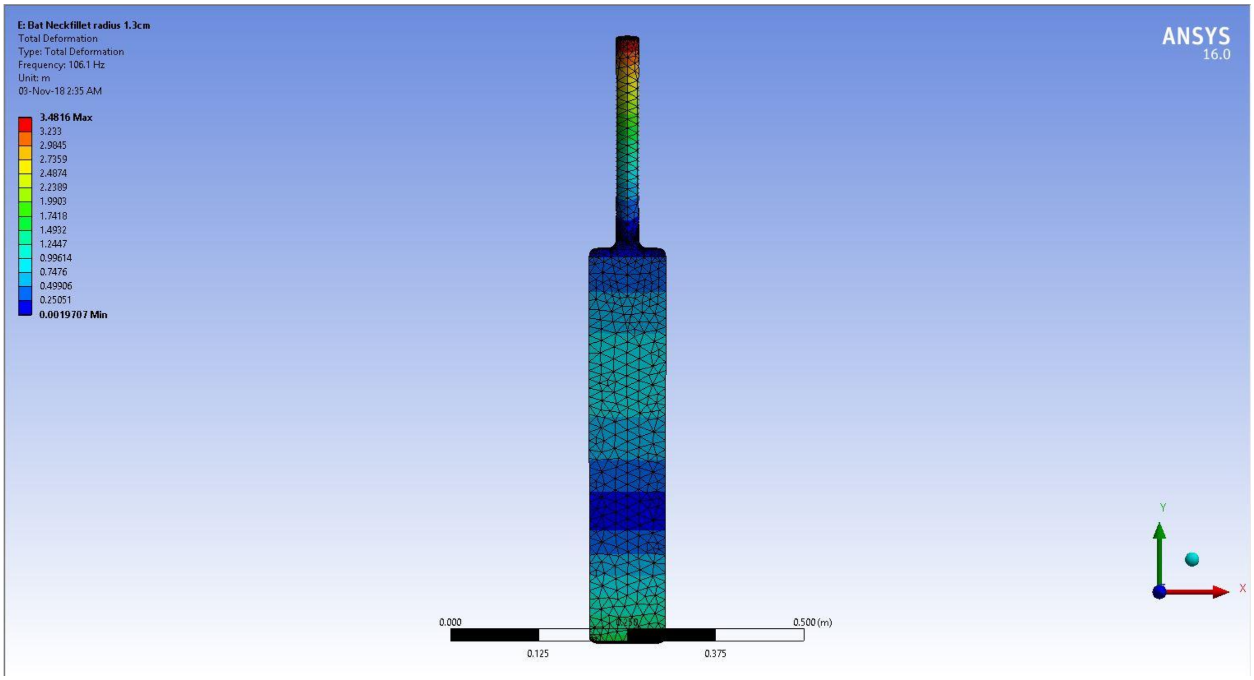

Figure 3.6: Modal Analysis for Neck Fillet Radius 13 mm

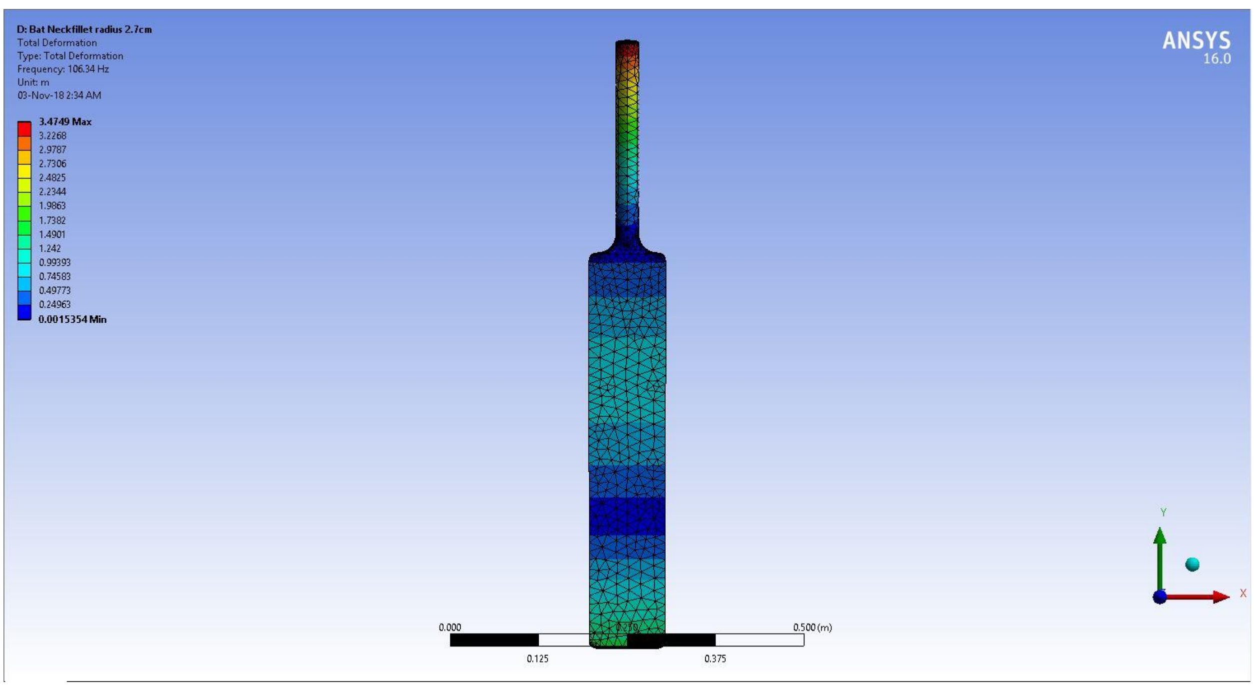

Figure 3.7: Modal Analysis for Neck Fillet Radius 27 mm

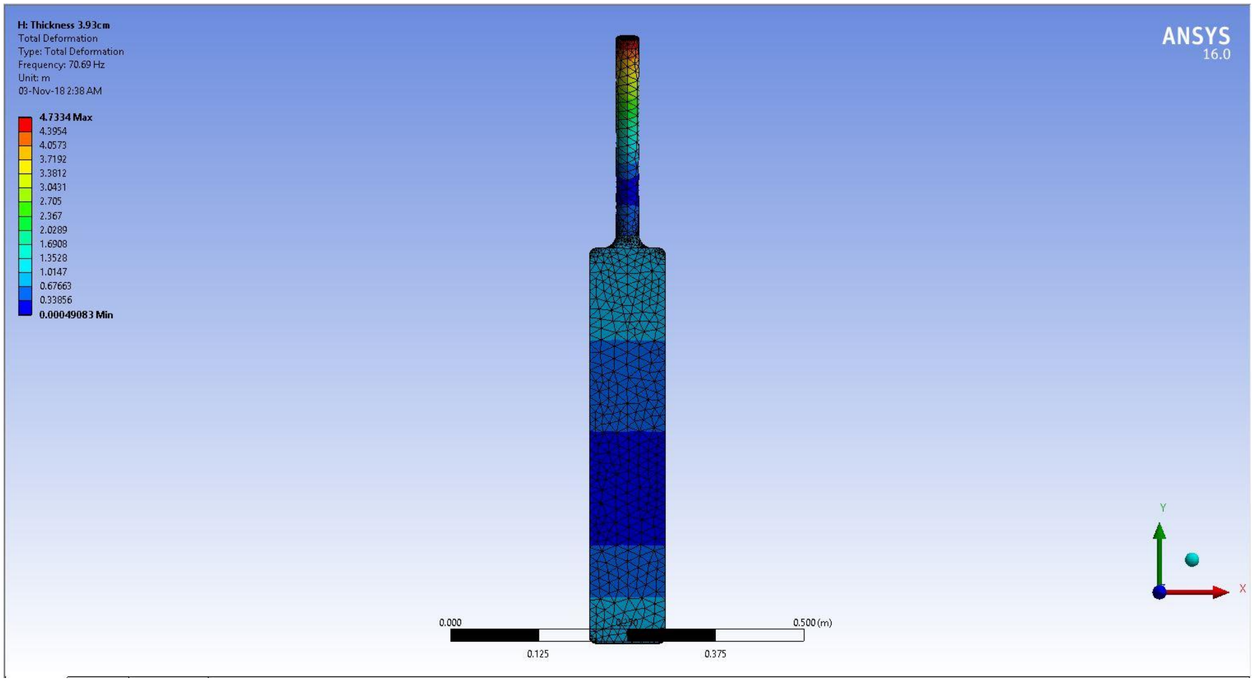

Figure 3.8: Modal Analysis for Thickness 39.3 mm

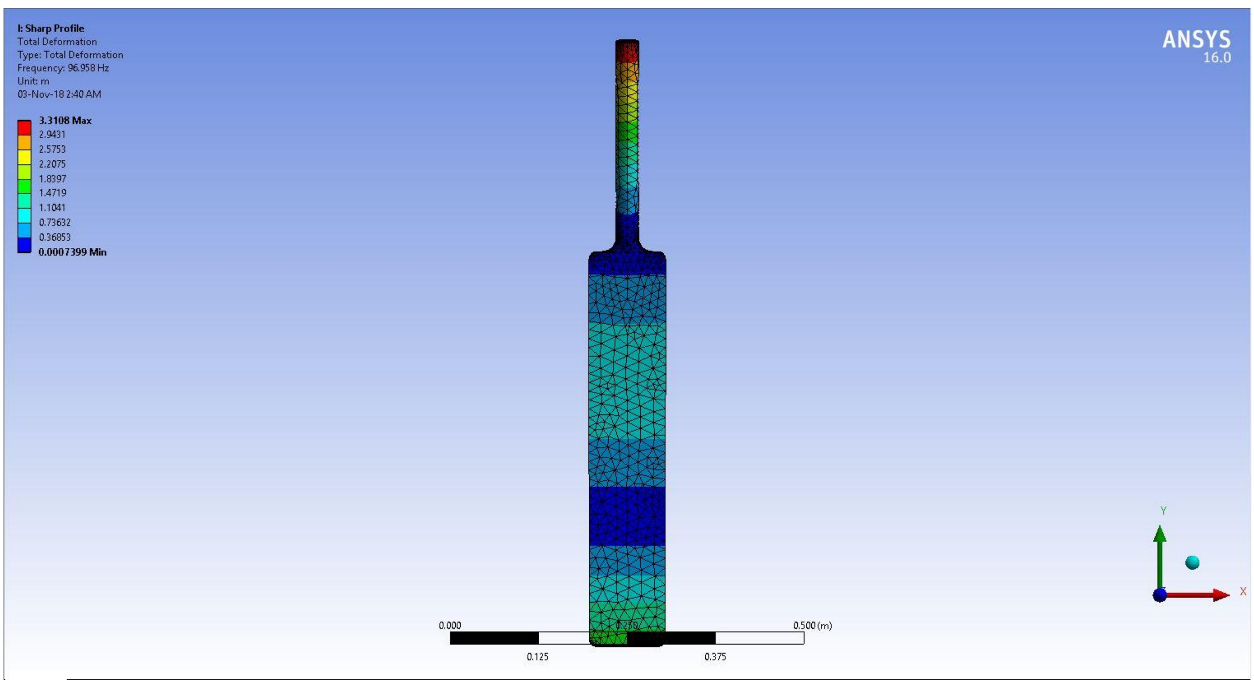

Figure 3.9: Modal Analysis for Sharp Spine

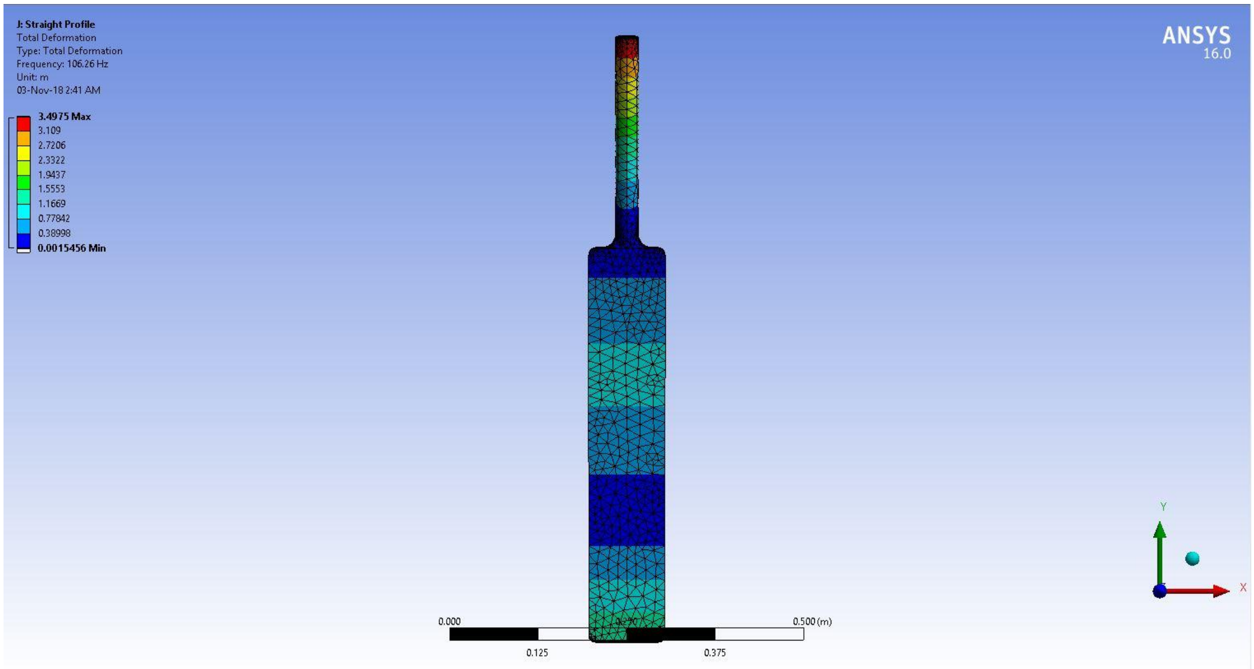

Figure 3.10: Modal Analysis for Straight Spine

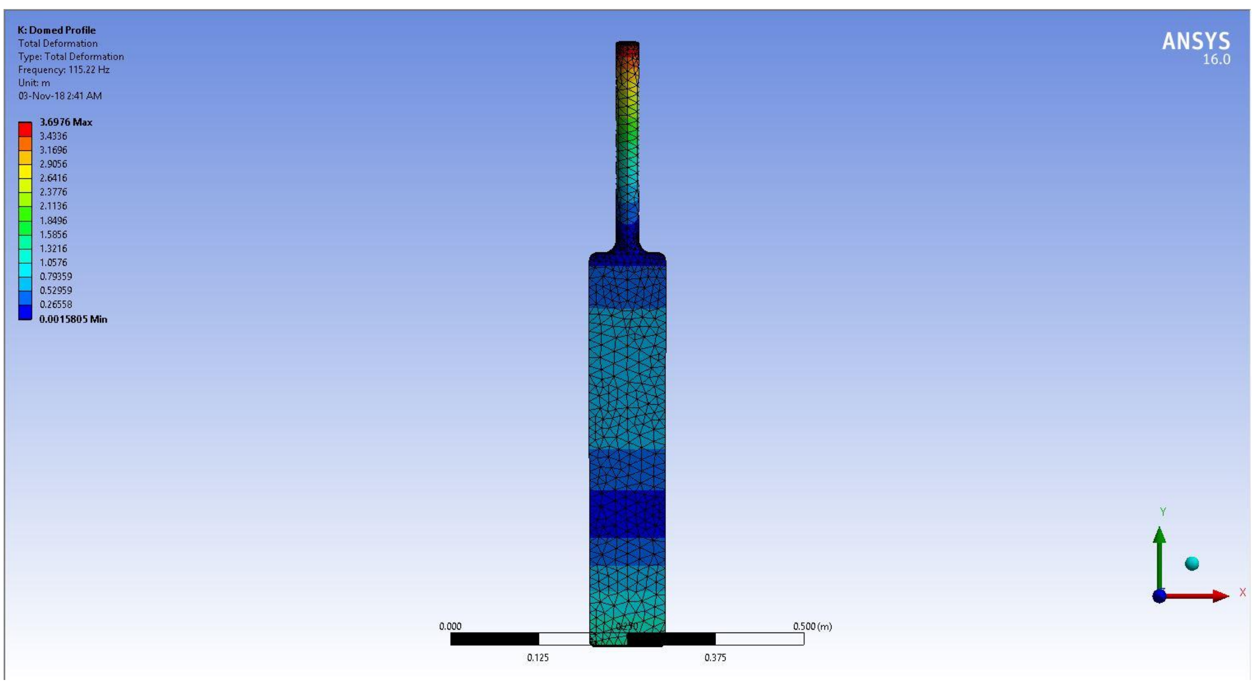

Figure 3.11: Modal Analysis for Domed Spine

The most significant effect of the changing parameter upon the sweet spot and the minimum deformation was observed for the spines. Therefore the proposed optimum design was to be obtained by modification and optimization of the spine profile.

Chapter 4

The Final Modified Design

4.1 Design Modification

Since the most significant impact of the changing parameter was observed for the spine profile, the hypothesis for the optimized design was proposed according to the spine profile.

The minimum deformation was obtained for the domed profile shape because of the advantage of having some extra material. While for the generic design for the traditional cricket bat, the sharp spine provides structural support like a vertebrae to the cricket bat from the stress due to the impact of cricket ball during playing a shot.

Figure 4.1: Sharp spine profile (left) and Domed spine profile (right)

Therefore, the proposed design of the spine was made in iteration to the domed profile and the sharp profile

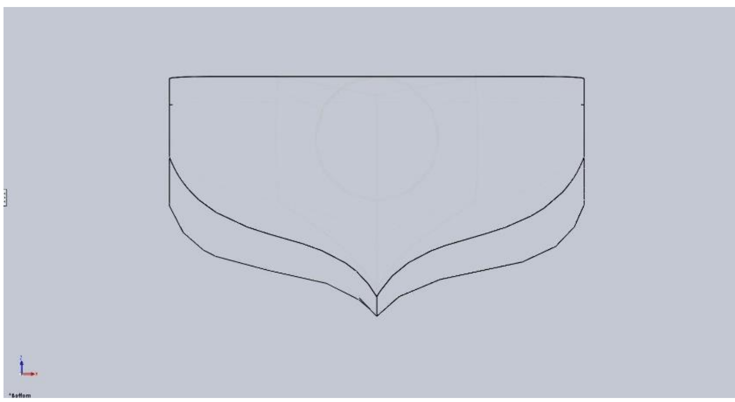

Figure 4.2: Modified spine profile

4.2 Design

The CAD model of the modified cricket bat was created in Solidworks 2015. Shape and the dimensions of the bat were very finely scrutinized and kept well under the regulations of ICC as a standard sized cricket bat.

The bat was designed maintaining the following parameters:

- Face Width – 108 mm
- Blade Height – 559 mm
- Edge Thickness – 25 mm
- Neck Fillet Radius – 20 mm

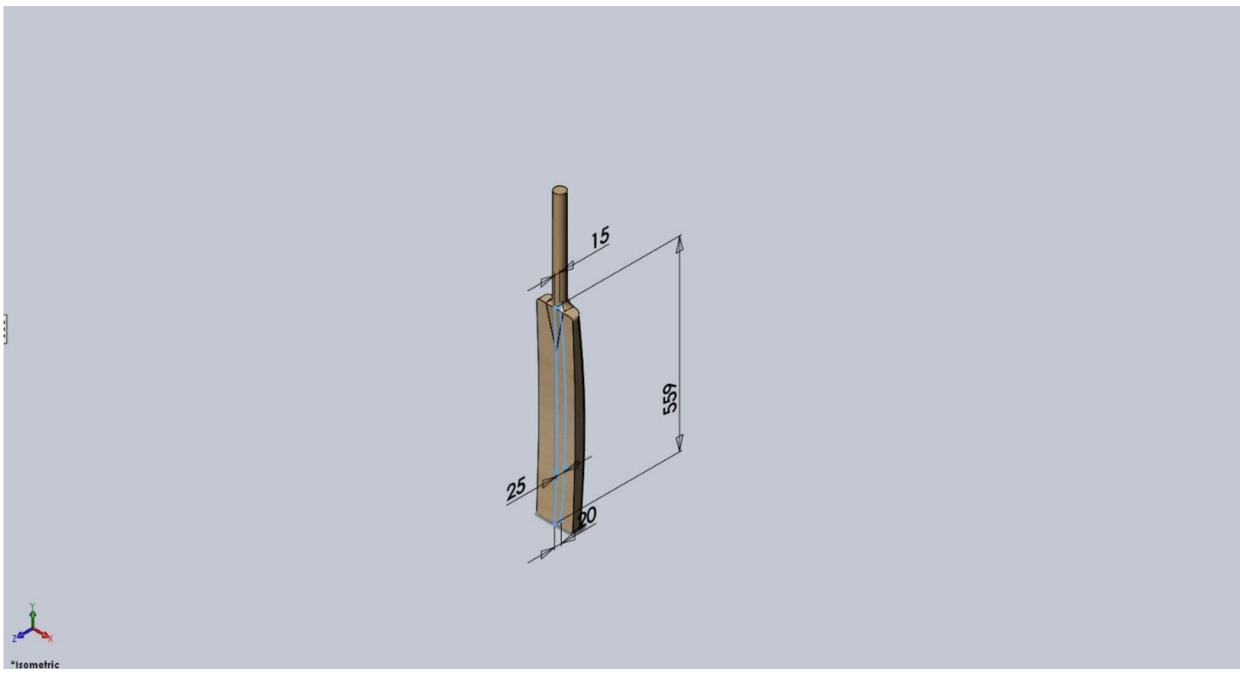

Figure 4.3: Isometric view of the modified bat CAD model

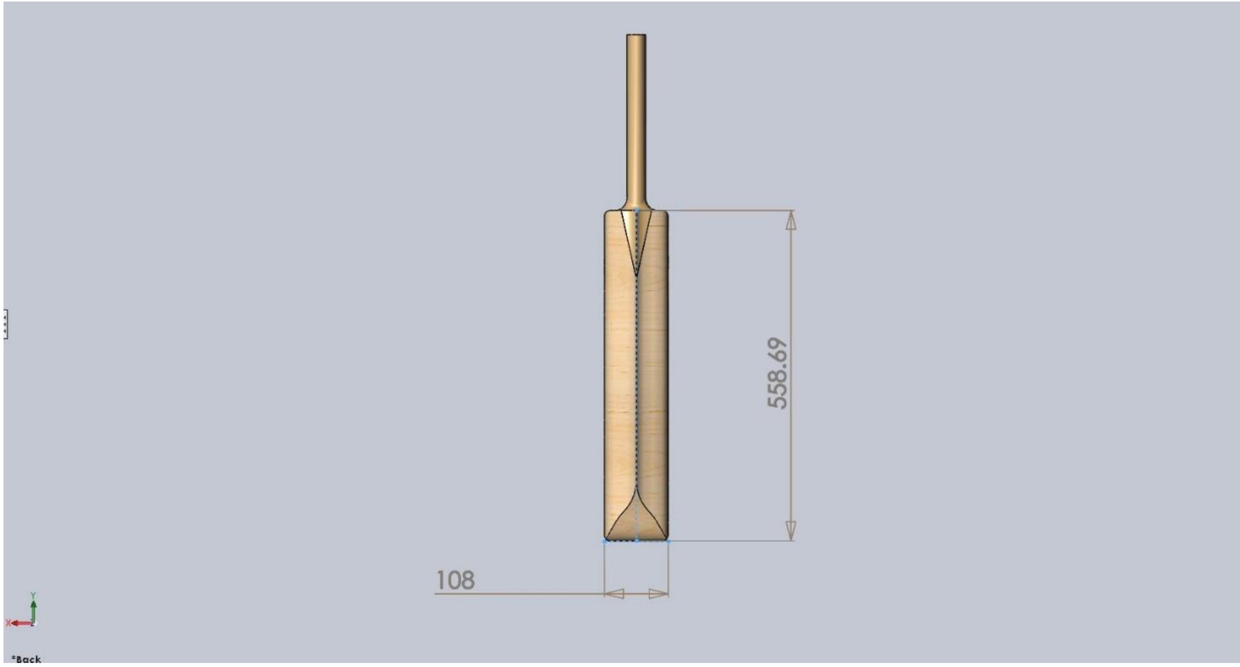

Figure 4.4: Front view of the traditional bat CAD model

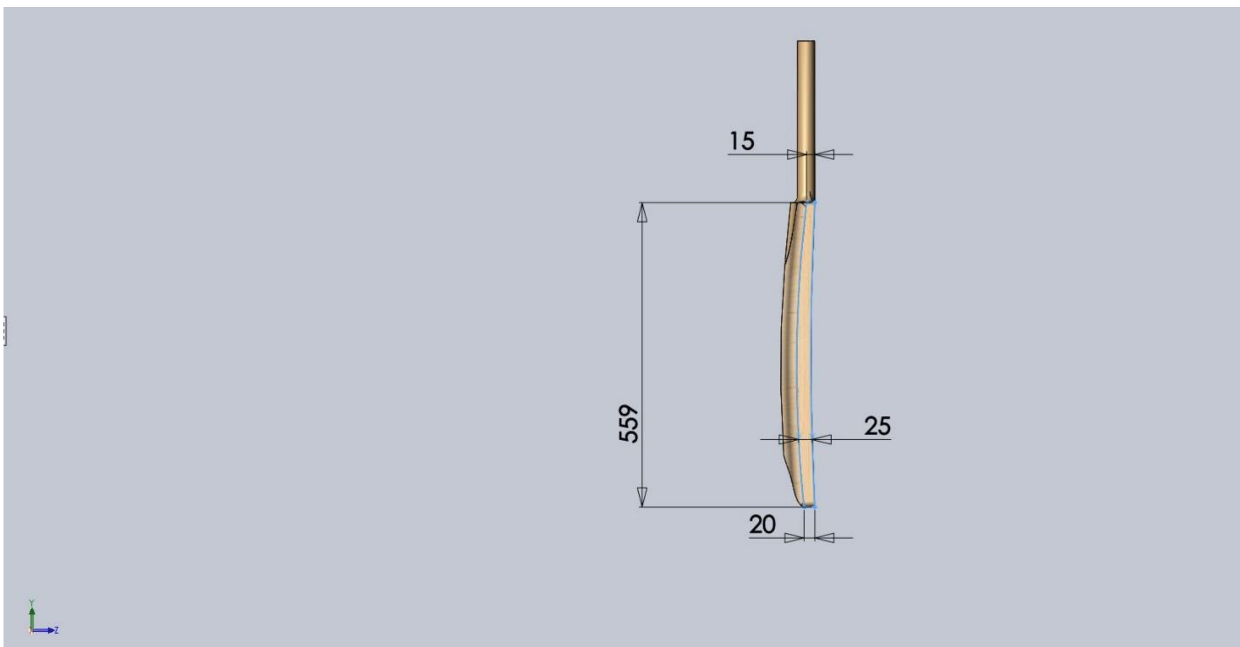

Figure 4.5: Side view of the traditional bat CAD model

4.3 Simulation

The simulations of the model created are performed in ANSYS Workbench 16. At first, the CAD model was loaded in to the workbench and materials were assigned for the individual parts. Then, Finite Element Modeling or Meshing was done. Followed to that, Modal Analysis was performed on the meshed model to determine the Natural Frequency. And finally, the total deformation was calculated and mapped for the meshed model.

4.3.1 Finite Element Modeling

The parts of the model were assigned with each individual materials as per Table 1.2. The handle is assigned to have Cane as material, while the blade is assigned with English willow wood. The physical properties were input to the workbench.

Model (L4) > Geometry

Object Name	*Geometry*
State	Fully Defined
Definition	
Source	E:\THESIS 2018\IGs\Developed profile.IGS
Type	Iges
Length Unit	Meters
Element Control	Program Controlled
Display Style	Body Color
Bounding Box	
Length X	0.108 m
Length Y	0.856 m
Length Z	6.2738e-002 m
Properties	
Volume	2.6209e-003 m^3
Mass	1.4077 kg
Scale Factor Value	1.
Statistics	
Bodies	2
Active Bodies	2
Nodes	38692
Elements	25732
Mesh Metric	None

Figure 4.6: Geometry data of the modified bat simulation

Model (L4) > Geometry > Parts

Object Name	*Part 1*	*Part 2*
State	Meshed	
Graphics Properties		
Visible	Yes	
Transparency	1	
Definition		
Suppressed	No	
Stiffness Behavior	Flexible	
Coordinate System	Default Coordinate System	
Reference Temperature	By Environment	
Material		
Assignment	English Wllow Wood	Cane
Nonlinear Effects	Yes	
Thermal Strain Effects	Yes	
Bounding Box		
Length X	0.108 m	5.2565e-002 m
Length Y	0.56155 m	0.413 m
Length Z	6.2738e-002 m	5.5228e-002 m
Properties		
Volume	2.2553e-003 m^3	3.6559e-004 m^3
Mass	1.2066 kg	0.20107 kg
Centroid X	0.21209 m	0.2121 m
Centroid Y	-0.13751 m	0.24199 m
Centroid Z	0.26542 m	0.2727 m
Moment of Inertia Ip1	2.6591e-002 kg·m^2	2.6261e-003 kg·m^2
Moment of Inertia Ip2	1.2756e-003 kg·m^2	3.4747e-005 kg·m^2
Moment of Inertia Ip3	2.7478e-002 kg·m^2	2.6231e-003 kg·m^2
Statistics		
Nodes	25803	12889
Elements	17121	8611
Mesh Metric	None	

Figure 4.7: Geometry data of the parts of modified bat simulation

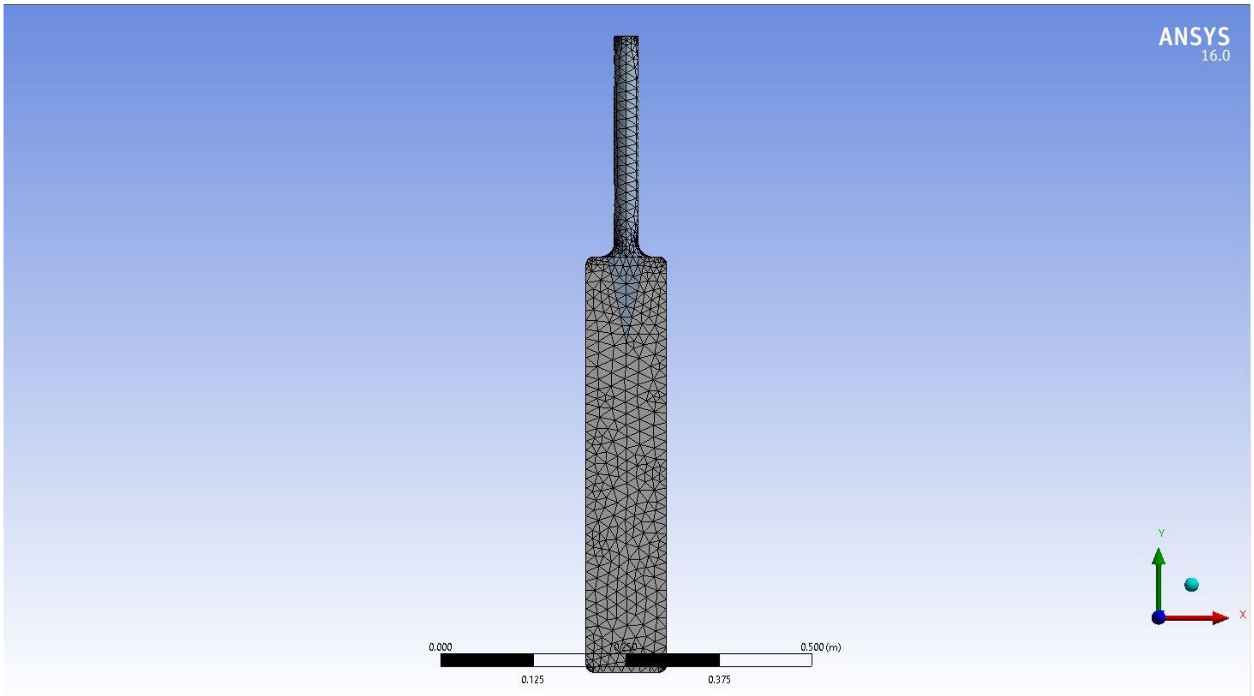

Figure 4.8: Finite Element Modeling (Meshing) of the modified bat

As according to the figure, the mesh was generated under ‘fine’ meshing to divide the whole assembly into small blocks of solids for the ease of calculations and simulations to be performed.

The generated mesh had 38692 nodes and 25732 elements.
The minimum mesh length was 1.0288e-003 m.

Model (L4) > Mesh	
Object Name	*Mesh*
State	Solved
Display	
Display Style	Body Color
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Fine
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	High
Transition	Slow
Span Angle Center	Fine
Minimum Edge Length	1.0288e-003 m
Inflation	
Use Automatic Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Patch Independent Options	
Topology Checking	No

Figure 4.9: Meshing Data of the modified bat simulation

4.3.2 Modal Analysis

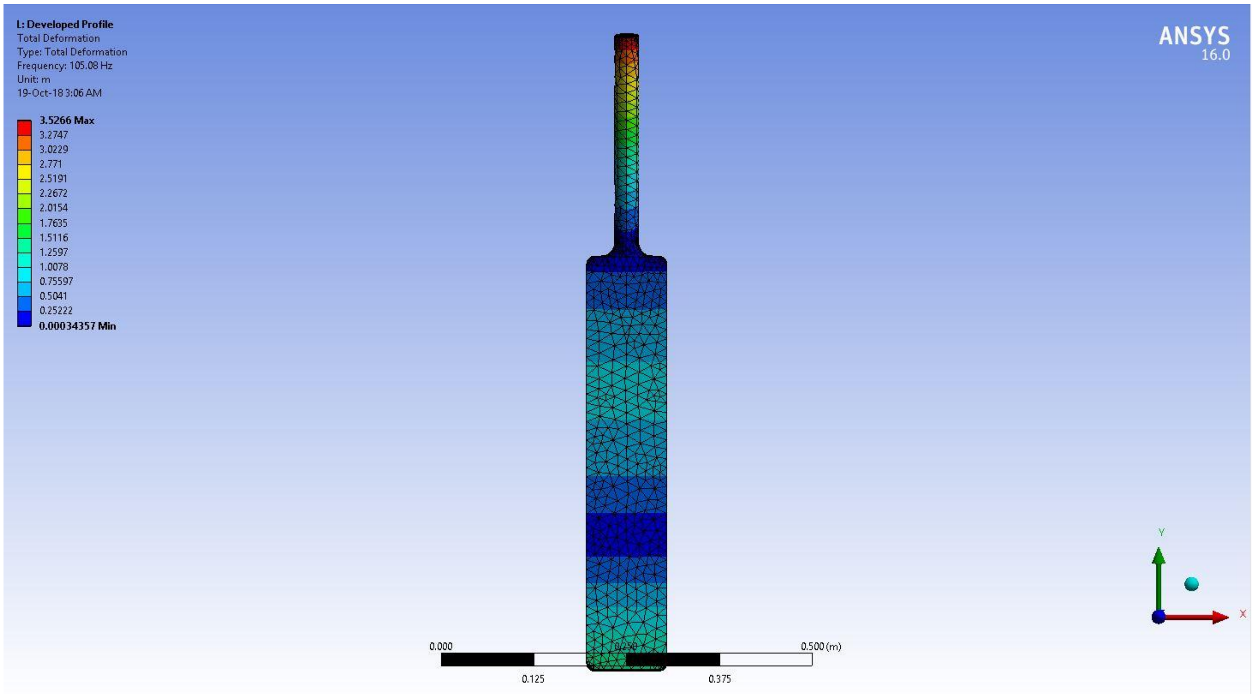

Figure 4.10: Modal Analysis of the modified cricket bat

Model (L4) > Modal (L5) > Solution (L6)

Mode	Frequency [Hz]
1.	0.
2.	
3.	
4.	
5.	9.3871e-004
6.	2.6216e-003
7.	105.08
8.	165.44
9.	250.83
10.	418.17
11.	471.37
12.	655.43
13.	760.16
14.	842.25
15.	1043.6
16.	1101.
17.	1195.4
18.	1232.4
19.	1368.
20.	1600.3

Figure 4.11: Frequencies under each modes for Modal Analysis of modified cricket bat

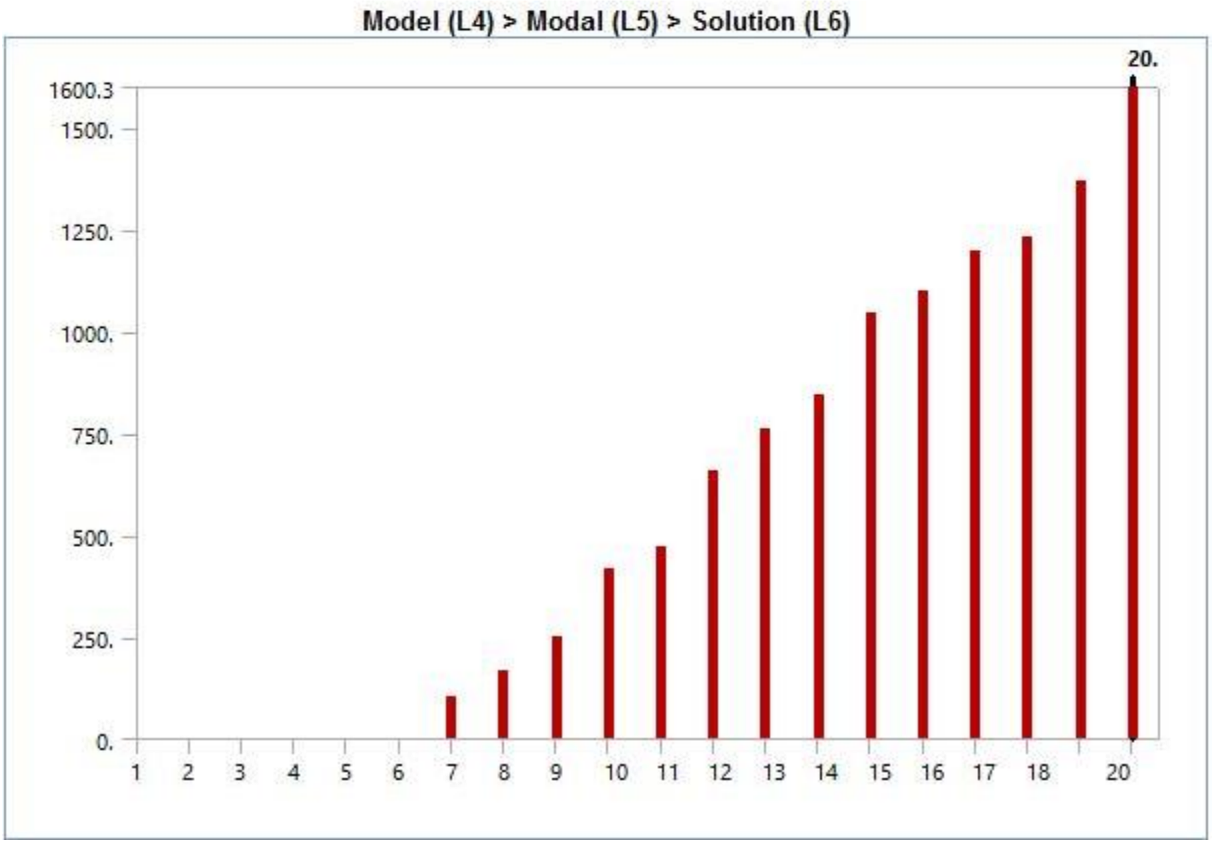

Figure 4.12: Frequency chart of Modal Analysis of the modified cricket bat

As seen in the figure, 7^{th} mode is selected since it gives the first natural frequency. The dark blue region indicates the minimum deformation of the whole assembly. The frequency of the 7^{th} mode was **105.08 Hz**, and the minimum deformation of the dark blue mapped region was **0.00034357m**.

4.4 Comparison of the Modified design with the Traditional design

The major significant change to the bat structure was only made to the spine profile of the bat.

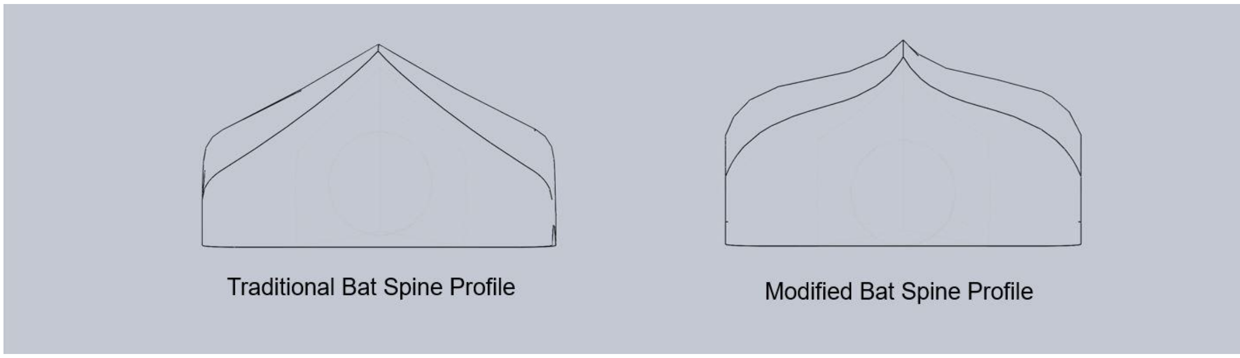

Figure 4.13: Traditional bat spine profile vs the modified spine profile

Because of this change in structure a very significant change is observed, in the minimum deformation and sweet spot stroke.

	Traditional Bat	**Modified Spine Bat**
Mass	1.2958 Kg	**1.4077 Kg**
Natural Frequency	106.18 Hz	105.08 Hz
Minimum Mesh Length	1.0114e-005	1.0288e-003
Number of Nodes	38657	38692
Number of Elements	25787	25732
Minimum Deformation	8.56 X 10^{-4} m	**3.43 X 10^{-4} m**

Table 4.1: Comparison of Modified bat with the Traditional Bat

Therefore according to the comparison, the Modified bat has minimum deformation lower than the traditional bat design. The mass of the bat is within the regulation limit set by ICC. Although the bat has slightly greater mass than the traditional bat, the decreased minimum deformation or increased stroke of the sweet spot shall give the batsman an advantage.

Chapter 5

Conclusion

The developed design of the cricket bat has the minimum deformation lower than the traditional bat design. This lower minimum deformation contributes to the sweet spot with a better stroke and greater exit velocity for the cricket ball after impact with the bat during the game.

Further experimentations may lead to establishing the results.

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