Failure Investigation of Badminton Racket Using Modal Analysis

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Abstract—From its humble beginnings in wood to its current slim geometry in high quality light weight carbon fiber composites, improvements in the badminton racket have largely been due to material advancements. The link between design and performance remains relatively poorly understood. Current rackets are designed heuristically, based on experience of the manufacturer and the player. The objective of this research is to add a scientific perspective to the design of badminton rackets, by studying the underlying physics of the game. The design of a badminton racket requires an understanding of the player, the racket, and how they interact in generating a stroke. The dynamics of the stroke can be used to assess their performance. Performance can be characterized in terms of power and control, which can respectively be quantified by the shuttlecock speed and the consistency of the stroke. Since the stroke involves both rigid-body and flexible-body dynamics of the racket it can be characterized by several stroke parameters such as racket head speed at impact from the rigid-body motion, and elastic deflection and elastic velocity at impact from the deformation behavior. This study based of the finite element method, a computer simulation method, to analys the dynamic property of racket and string. Three-dimensional model was created Creo according to the geometry of a Yonex made graphite Badminton racket. Using ANSYS is done to calculate the modal frequency and shape; the results are to be obtained for determination of the failure in the badminton racket frame.

Key words: Badminton racket, Shuttlecock, Stroke, Deformation, Modal Frequency

I. INTRODUCTION

From its humble beginnings in wood to its current slim geometry in high quality lightweight carbon fiber composites, improvements in the badminton racket have largely been due to material advancements. The link between design and performance remains relatively poorly understood. Current rackets are designed heuristically, based on experience of the manufacturer and the player. The objective of this thesis is to add a scientific perspective to the design of badminton rackets, by studying the underlying physics of the game. There are lots of effort that has been done by badminton racket manufacturer in order to enhance the racket performances such as improving the material used, optimizing the racket shape and weight. Traditionally, badminton racket frame was made from wood and oval head shape. Now a day, the evolution of racket design brings to new design which the latest is isometric head shape racket with much more good material. Badminton is commonly known as the fastest racket sport due to the shuttle speed compare to others racket sport. It was recorded that the fastest smash for badminton racket was about 421 km/hour. Thus we can see that badminton is a high intensity game that required a good agility and speed to the player. One of the factors that contribute to the increasing performance of the game is due to technology development on badminton racket. This evolution of badminton racket is to enhance the performance of the racket itself such as increase the accuracy and speed of the shuttlecock and at the same time help to increase the performance of players. Hitting shuttlecock on the right area or spot on racket face can give lot advantage such as reduce the jarring on the gripping handle, produce more accuracy and imparts maximum speed to the shuttlecock. However, there are still lacks of research on badminton racket about the characteristics and behavior of the exact spot or area on the racket that badminton player should hit the shuttlecock. Some theories from tennis racket research can be used in this investigation because of some similarity between both racket tennis and badminton. Based on tennis racket previous research, a great area or spot to hit the ball on a racket can be found anywhere on the longitudinal axis between the tip and throat depending on the incident speed of the ball. It doesn’t take a racket scientist to figure out that no single racket is the “world’s best racket”. Different players have different playing styles, and therefore prefer different rackets. The difficulty lies in finding an explanation for these preferences, and ultimately to start customizing the racket to the player. Currently, badminton rackets are largely developed using heuristic methods based on player intuition and experience, and subsequently evaluated player feedback. While this trial-and-error method can eventually lead to well-performing rackets, the design process could be improved and streamlined by an analytical approach. Designing a badminton racket requires both recognizing what performance characteristics are desired, as well as understanding how different racket properties will affect the performance. Basically, good design requires knowing what to achieve, and how to achieve it. Desirable qualities in a racket can be summed up by power and control. Performance characteristics can be deduced by understanding the game of badminton, the winning strategies and tactics used by expert players. A few statistical studies on various aspects of rallies during tournaments have been conducted, concluding that net, drop and block shots are the most effective return strokes (Tong and Hong, 2000), and smash is the most effective kill shot (Lee et al., 2005; Tong and Hong, 2000). This leads back to the concepts of power and control, where smash is a power stroke and net shots require more finesse and technical control over the racket. To understand the influence of the racket on performance, we should analyze the interaction between the racket and the shuttlecock, and the interaction between the racket and the player. The racket-shuttlecock interaction can be examined from a mechanical point of view, as a collision between two objects. The racket-player interaction is more complex, involving both the mechanical aspects of the racket and the biomechanical aspects of the player. Dynamics of the stroke are influenced primarily by the racket’s mass properties and the player’s skill and...
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strength. The deformation behavior of the racket is in turn influenced by the dynamics of the stroke as well as stiffness properties of the racket. The key to good racket design understands how all these interactions ultimately relate to performance. Literature on the badminton racket is rather slim, but studies involving other sporting implements, especially tennis rackets, could prove to be relevant.

A. Problem statement:
The failure in a badminton racket is due to various parameters. The failure can occur at the strings material, frame cross section, joints. Analysis of badminton racket for its failure on the frame is carried out in this project. The compressive force acts on the outer side of the frame due to the force acting on the strings. The strings are in tension while the frame undergoes the compression, when the shuttle cock hits the strings. Modal analysis of the badminton racket is done to determine the failure parameters. Natural frequency plays vital role in failure of a structure is to be found in the experimental analysis as well as in FEA analysis.

B. Objectives:
- Modal analysis is to be done using analytical method and validate experimentally to find the natural frequency of the badminton racket
- The study is to be done on the effects of different cross sections on the failure of the frame. The preference is mostly on failure of oval shaped badminton racket.

C. Scope:
The research is oriented to determine failure of the frame for the oval shaped badminton racket. The different cross sections of the badminton racket frame can be studied for a better quality and performance. Suggest the perfect string arrangement for better performance of a badminton racket. Experimental modal analysis of the badminton racket is to be done. Various parameters behind the failure of the badminton racket frame are found which are to be used in the FEA analysis of the same simulated racket model.

D. Methodology:
The experiment is carried on a badminton racket to get the necessary parameters for its failure. The modal analysis using the FFT analyzer is done and the frequency response for various excitation forces is noted. The simulation of the tested badminton model is completed using CAD software. Modal analysis is to be done by using FEA software (ANSYS) with parameters obtained in experimental analysis. Results obtained from the experimental analysis are validated using FEA analysis. The experimental setup consists of FFT analyzer, accelerometer, impact hammer, badminton racket, stand for holding badminton racket. The working procedure for experimental analysis is that the badminton racket is fixed on the holding stand by mounting the accelerometer on the frame which is connected to FFT analyzer. Method which we are following is roving hammer in which accelerometer is fixed and impact hammer is roving. The impacting is to be done by impact hammer on different positions on the frame to determine the natural frequency.

II. MODELING OF BADMINTON RACKET

A. Selection of Badminton Racket:
- The badminton racket used in the research is Yonex Arotous 33.
- The frame material is composite (Carbon Graphite) and the string is made of Nylon 66
- The Badminton Racket is single casted racket having no T-joint at the head and rod.

B. Tracing the dimensions of the Badminton Racket:
The dimensions were obtained after tracing the Badminton Racket on a plain paper. The obtained dimensions are as follow:

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Part Name</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Major diameter of head</td>
<td>250 mm</td>
</tr>
<tr>
<td>2</td>
<td>Minor diameter of head</td>
<td>200 mm</td>
</tr>
<tr>
<td>3</td>
<td>Shaft length</td>
<td>210 mm</td>
</tr>
<tr>
<td>4</td>
<td>Handle length</td>
<td>150 mm</td>
</tr>
</tbody>
</table>

Table 1: Dimensions of Badminton Racket

C. Modeling of frame, cap and handle:
The dimensions obtained in second step are used for the modeling of frame, cap and handle. All dimensions are in mm with appropriate accuracy. The thickness of the head is found by breaking the racket and measuring its profile. The thickness found to be 2 mm. The holes on the head are measured to be 72. Holes are formed such that the axis is perpendicular to the head surfaces which are shown in Fig.2.
D. Study of stringing method:
The string woven in the head have various standard patterns. The strings are pre-tensioned to a force of 22 lbs. The tension can be in a range of 18 lbs to 24 lbs. The study was done for various string arrangements and from those an appropriate method was selected as shown in Fig.3.

E. Modeling of string in Assembly:
The assembly generated in step 2 is then used for stringing the string in the head of Badminton Racket. The selected pattern in step 4 is followed for stringing. The stringing is done directly in assembly. The entire assembly is shown in Fig 4.

III. MODAL ANALYSIS
Modal analysis is the study of the dynamic properties of structures under vibration excitation. Modal analysis is the field of measuring and analyzing the dynamic response of structures and or fluids during excitation. Examples would include measuring the vibration of a car’s body when it is attached to an electromagnetic shaker, or the noise pattern in a room when excited by a loudspeaker. Modern day modal analysis systems are composed of 1) sensors such as transducers (typically accelerometers, load cells), or non-contact via a Laser vibrometer, or stereo photogrammetric cameras 2) data acquisition system and an analog-to-digital converter frontend (to digitize analog instrumentation signals) and 3) host PC (personal computer) to view the data and analyze it. Classically this was done with a SIMO (single-input, multiple-output) approach, that is, one excitation point, and then the response is measured at many other points. In the past a hammer survey, using a fixed accelerometer and a roving hammer as excitation, gave a MISO (multiple-input, single-output) analysis, which is mathematically identical to SIMO, due to the principle of reciprocity. In recent years MIMO (multi-input, multiple-output) have become more practical, where partial coherence analysis identifies which part of the response comes from which excitation source. Using multiple shakers leads to a uniform distribution of the energy over the entire structure and a better coherence in the measurement. A single shaker may not effectively excite all the modes of a structure. Typical excitation signals can be classed as impulse, broadband, swept sine, chirp, and possibly others. Each has its own advantages and disadvantages. The analysis of the signals typically relies on Fourier analysis. The resulting transfer function will show one or more resonances, whose characteristic mass, frequency and damping can be estimated from the measurements. The animated display of the mode shape is very useful to NVH (noise, vibration, and harshness) engineers. The results can also be used to correlate with finite element analysis normal mode solutions.

A. Modal Analysis in ANSYS:
Modal analysis is carried out in free-free condition in order to analyze the natural frequency of the racket. Basically ANSYS solver works on following steps:
The steps to do a modal analysis are as follows:
1) Preprocessing
   - Geometry
   - Meshing
2) Solution
   - Analysis Type and Options
   - Loading
   - Solve
3) Post processing
   - Review results

B. Geometry and meshing:
Same considerations as a static analysis are done. Include as many details as necessary to sufficiently represent model geometry. A fine mesh will be needed to resolve complex mode shapes.
C. Plotting results:
Results are plotted such as the maximum frequency of vibration. Mode shapes formed during deformation. The natural frequency of the structure can easily be found in modal analysis.

1) Import Geometry
The geometry created in the Creo software is in the assembly format, has been converted into the IGES format to be used in the ANSYS. The geometry is then called in the ANSYS Workbench software and generated in the work window.

2) Engineering Data
The geometry consists of four parts made out of four different materials. The each material has its own physical properties such as density, Poisson’s ratio, Young’s modulus. The properties for each parts are given in table below:

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Part Name</th>
<th>Density (Kg/m³)</th>
<th>Young’s Modulus (Mpa)</th>
<th>Poisson’s ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Frame</td>
<td>2490</td>
<td>4100</td>
<td>0.17</td>
</tr>
<tr>
<td>2</td>
<td>String</td>
<td>1130</td>
<td>2520</td>
<td>0.4</td>
</tr>
<tr>
<td>3</td>
<td>Cap</td>
<td>1030</td>
<td>3000</td>
<td>0.34</td>
</tr>
<tr>
<td>4</td>
<td>Handle</td>
<td>850</td>
<td>11000</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Table 2: Selection of Material Properties

3) Meshing
Meshing is the division of the geometry into number of small parts called elements. The perfect meshing is the most essential part of any analysis in ANSYS. The selected element size for the meshing is 9 mm. The all four parts of the badminton racket geometry were meshed with same element size. The element size selection is done with plotting the graphs for different elements varied from 6 mm to 10 mm with interval of 0.5 mm. The most suitable curve is shown for the element size 9 mm. The advanced settings were used for the perfect meshing, as the geometry is very complex with multiple curves and holes. As the curved frame consists of holes of 2 mm diameter the advanced sizing function also used for the curvature option available in ANSYS software. The graph of frequency v/s element size is shown in fig.7, and element size is confirmed by comparing the global modes i.e. mode no. starting from 7.

4) Solving
The equations formed in the background are solved to obtain the natural frequencies up to 16 mode. The first 6 mode compensate for the 6 degrees of freedom which are almost equal to zero hence neglected.

5) Plotting the Results
The results are obtained in the form of the natural frequency and deformation. The deformation regions are seen in the animation obtained.

The results obtained by using ANSYS software are as follows:

<table>
<thead>
<tr>
<th>Mode No.</th>
<th>Frequency (Hz)</th>
<th>Mode No.</th>
<th>Frequency (Hz)</th>
<th>Mode No.</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>7</td>
<td>32.76</td>
<td>13</td>
<td>148.25</td>
</tr>
<tr>
<td>2</td>
<td>5.38e-4</td>
<td>8</td>
<td>60.95</td>
<td>14</td>
<td>169.48</td>
</tr>
<tr>
<td>3</td>
<td>8.17e-4</td>
<td>9</td>
<td>78.39</td>
<td>15</td>
<td>171.58</td>
</tr>
<tr>
<td>4</td>
<td>1.3018e-3</td>
<td>10</td>
<td>98.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2.14e-3</td>
<td>11</td>
<td>122.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>5.71e-3</td>
<td>12</td>
<td>124.81</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Obtained frequencies from ANSYS
In free free-modal analysis values of first six modes are equal to zero for six different degrees of freedom. In above result table values of 15 different modes are given with respect to their natural frequencies. The values of natural frequencies are increasing with respect to mode points. After comparing with the experimental analysis the resonance frequency obtained is 58.594Hz.

Fig. 6: Steps in ANSYS for Modal Analysis

Fig. 7: Graph of Frequency vs element size

Fig. 8: Regions of failure of Badminton Racket
The above fig shows the regions of failure of racket. The single cast Badminton Racket fails mostly on frame head. The maximum possible failure region shown in red color occurs in between 9 O’clock to 3 O’clock.

Further the observed natural frequencies are compared with the experimental modal analysis which is described in further.

IV. EXPERIMENTAL VALIDATION

The results obtained in ANSYS software are validated with the results obtained from the experimental analysis. The experimental setup consists of FFT analyzer, accelerometer, impact hammer, badminton racket, stand for holding badminton racket. The working procedure for experimental analysis is that the badminton racket is fixed on the holding stand by mounting the accelerometer on the frame which is connected to FFT analyzer. Method which was followed was roving hammer in which accelerometer was fixed and impact hammer is roving. The impacting is done by impact hammer on different positions on the frame to determine the natural frequency. Another method was used in which the badminton racket was freely hanging and the accelerometer mounted on the frame, impact was done at various points with the impact hammer. The DIVIS software was used in the FFT to analysis the input and output of the sensors.

Instruments used in Experimental Setup

A. Accelerometer:
Accelerometer is a sensor which used for measuring acceleration, frequency, vibration, model testing etc. The accelerometer used in this experimental setup is uni-axial that allows discrimination of behavior of patterns which measures overall acceleration and frequency of the Badminton Racket.

B. Impact hammer:
Impact hammer testing involves striking a mechanical structure with and instrumented hammer and collecting response information from transducer mounted on the structure the response from single accelerometer yields transfer and transactional characteristics of the structure. The integration of response information from multiple accelerometers at various points of interest allows for modal analysis. The hammer exist resonance frequency in this structure over a broad range the physical properties of hammer and the strike velocity determine the amplitude and the frequency content in the force impulse. Extender masses can be used to concentrate more energy at lower frequencies.
The accelerometer can be seen in the above image connected to the badminton racket frame. The accelerometer was fixed on the point where the badminton racket rod is connected to the badminton racket frame. The accelerometer is uni-axial which gives the signals for the motion of the badminton racket in the direction of the hammer impact.

Results obtained with first method are as follow:

<table>
<thead>
<tr>
<th>Mode No.</th>
<th>Frequency (Hz)</th>
<th>Mode No.</th>
<th>Frequency (Hz)</th>
<th>Mode No.</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>29.297</td>
<td>7</td>
<td>58.594</td>
<td>13</td>
<td>63.477</td>
</tr>
<tr>
<td>2</td>
<td>34.180</td>
<td>8</td>
<td>39.063</td>
<td>14</td>
<td>68.359</td>
</tr>
<tr>
<td>3</td>
<td>34.180</td>
<td>8</td>
<td>39.063</td>
<td>14</td>
<td>68.359</td>
</tr>
<tr>
<td>4</td>
<td>34.180</td>
<td>8</td>
<td>39.063</td>
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<td>34.180</td>
<td>8</td>
<td>39.063</td>
<td>14</td>
<td>68.359</td>
</tr>
<tr>
<td>6</td>
<td>34.180</td>
<td>8</td>
<td>39.063</td>
<td>14</td>
<td>68.359</td>
</tr>
</tbody>
</table>

Table 4: Obtained frequencies Experimental Modal Analysis (Method-1)

The above result table shows the values of natural frequencies for different mode shapes. The result was tabulated for 15 modes, comparing with analytical the resonant frequency obtained for 7th mode 34.180Hz and it increases with increase in mode shape.

The above graph shows spectrum of peak values of frequency at various mode points for first method.

2) In second method, The Badminton Racket was freely suspended in the air by hanging the racket with the bar at its two points. The accelerometer was fixed at one point and with the help of roving hammer the readings were recorded at 16 different mode points as shown in fig below:

Result obtained with second method are given below:

<table>
<thead>
<tr>
<th>Mode No.</th>
<th>Frequency (Hz)</th>
<th>Mode No.</th>
<th>Frequency (Hz)</th>
<th>Mode No.</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>34.619</td>
<td>7</td>
<td>139.346</td>
<td>13</td>
<td>176.117</td>
</tr>
<tr>
<td>2</td>
<td>58.631</td>
<td>8</td>
<td>176.117</td>
<td>14</td>
<td>181.146</td>
</tr>
<tr>
<td>3</td>
<td>74.569</td>
<td>9</td>
<td>120.768</td>
<td>15</td>
<td>123.459</td>
</tr>
<tr>
<td>4</td>
<td>92.015</td>
<td>10</td>
<td>123.459</td>
<td>16</td>
<td>123.459</td>
</tr>
<tr>
<td>5</td>
<td>120.768</td>
<td>11</td>
<td>123.459</td>
<td>16</td>
<td>123.459</td>
</tr>
<tr>
<td>6</td>
<td>120.768</td>
<td>11</td>
<td>123.459</td>
<td>16</td>
<td>123.459</td>
</tr>
</tbody>
</table>

Table 5: Obtained frequencies Experimental Modal Analysis (Method-2)

The above result table shows the values of natural frequencies for different mode shapes. The result was tabulated for 15 modes. The values of first 6 modes are approximately equal to zero. Comparing the result of analytical and experimental the values of 7th and 8th mode shape are same having error less than 5%. The resonant natural frequency obtained from both analytical and experimental is in the range of 56-60 Hz.

The above graph shows spectrum of peak values of frequency at various mode points for first method.

V. RESULT AND DISCUSSION

A. Analytical method:

By using ANSYS software, modal analysis was done to obtain natural frequencies of badminton racket. The analytical results for natural frequencies were obtained in the software by assigning the physical properties, contacts, number of modes to the respective parts of Badminton racket.

B. Experimental method:

The experimental work was done by using two methods. In first method the plywood setup was used to obtain the results with the help of accelerometer, impact hammer, FFT
The conclusions are obtained after comparing the results of analytical and experimental modal analysis carried out in project work. The analytical modal analysis was performed in the ANSYS software and the Experimental analysis with the help of the FFT analyzer, impact hammer, accelerometer.

The conclusions obtained from the above explained procedures are as follows

[1] The modal analysis has identified the inherent structural dynamic properties of the badminton racket. Natural frequencies of the test rackets have been identified with mode shapes.

[2] After comparing both analytical and experimental we came to conclusion that the obtained natural frequency of badminton racket is in the range 56–60Hz. Therefore, the racket will possibly fail at these frequencies.


[4] The principles could also be applied to other sports equipment such as squash rackets, cricket bats, baseball bats or hockey sticks.

REFERENCES


[5] Yao-dong Gu , Jian-she Li "Dynamic Simulation of Tennis Racket and String" Faculty of Physical Education,Ningbo University, Ningbo, Zhejiang, P.R.China (2006)


[10] Hiroshi Meada "Kinematic analysis of three different badminton backhand overhead strokes" Tsai National Taiwan Normal University, Taipei, Taiwan ,National Taiwan Ocean University, Keelung, Taiwan(2002)

[12] Fakhrizal Azmy Nasruddin1, Muhamad Noor Harun1 Ardiyansyah Syahrom1, Mohammed Rafiq Abdul Kadir, Abdul Hafidz Omar "Coefficient of Restitution in Badminton Racket" International Conference on Design and Concurrent Engineering Universiti Teknikal Malaysia Melaka (UTeM) (2012)


[15] Tanawat Vanasant1, Somjarod Mingkhumlert1, Weerawat Limroongreungrat2 "The effect of string tension on shuttlecock velocity"


[18] Ning Yang "Research on badminton forehand smash hand technology based on biomechanical analysis” (2013)