**Design, Analysis and Development of Force Plate for Prosthetic Application**

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**Abstract.** The present work is aimed at "Design and Development of a Force plate" and also to study the effect of different variable loads over the components ground reaction forces by different material properties to obtain the optimized result. By using realistic materials, accurate results will be achieved. Force Plate is modelled and designed using PRO-E and for checking performance analysis and to check its durability by Fatigue Analysis, ANSYS Workbench is employed. The results conclude that stainless steel and structural steel materials are suitable for better efficient working of force plate. This paper deals with the best process of force plate design by considering gait analysis for cost Prosthetic manufacturing.

**Keywords.** Force Plate, Gait Analysis, Prosthetic Manufacturing, Bio-Mechanics

1. **Introduction**

A Force plate is designed to calculate the force and moments of a ground reaction force applied to its top surface. It can be subjected to force by standing, stepping, or jumping on it. Force plates are systematically used in research and scientific studies looking at evenness[1], gait and sports performance. Force plate can also be used as tutelage benevolence in undergraduate physics classes to manifest appositeness between Force, Acceleration, Velocity, and Displacement[2].

A force plate usually consists of one or more sensors attached to it to give an electric proportion the force on the plate[3]. It performs the same function as that of a weighing scale. The application of a force plate is to measure the ground reaction force on each foot while standing, walking, running, and jumping[2].

The measurement of ground reaction forces has been a valuable source of information in the study of human motion. The force plate as a measuring instrument has been used in wide range studies in areas of gait, sport, human power output, neural control and the maintenance of balance.

Gait studies using force plate data form a major part of research in biomechanics. Force plates have also been used by physiologists and biomechanists to examine human output.

The effects of different synthetic sports surfaces on ground reaction forces when landing on them is studied, but the most extensive study of the influence of surface materials on impact forces have been undertaken in the design of the running shoes. A similar investigation was also concentrated upon the influence of different tennis shoe manufacturing on discomfort and pain experienced. This was a comprehensive study with force plate data on over 200 subjects recorded. The data obtained from the force plate analysis have been used in Bio-mechanical studies for calculating long jump take offs.

Variations on human vertical jump have been investigated with force plates since the first pneumatic devices were invented[4].

2. **Methodology**

2.1. **Design and Modeling**

Force Plate prototype developed in this study is in the shape of rectangle with one sensor attached between the plates. The dimensions of the plate are 13mm*13mm at the top surface and 15mm*15mm at the bottom surface. There are two fixed supports for each plate with provision for proper alignment. The force applied is in the vertical direction (Y direction). Material used for force plates is stainless steel and for load cell is aluminium alloy.[5]

The base frame is comparatively larger than top frame due as the base frame acts as a beam (fixed support). The component is modelled using Pro-E.
It consists of two frames i.e., top and bottom frames. A load cell sensor is placed between the frame which is made up of aluminium alloy. Four bolts are used to join the frames and the sensor. Top frame is covered with aluminium sheet shown in figure 1.

The above figure shows the assembled view of force plate, where frames and sensor are fixed with help of bolts and top frame is covered with aluminium sheet.

2.2. Analysis

The Force Plate model was developed using Pro-E CREO 3.0 and analysis was performed in ANSYS WORKBENCH and results were obtained. Then each part of model was assigned with required material of different combinations such as:

1. Copper – Aluminium – Copper
2. Grey Cast Iron-Aluminium-Grey Cast Iron
3. Structural Steel-Aluminium-Structural Steel
4. Stainless Steel-Aluminium-Stainless Steel

Then triangular surface meshing has been done for entire Force Plate.

The Nodes used are 215669 and Elements used are 107323. The bottom frame is given a constraint called Fixed Support, and the upper frame with the Pressure constraint. It is an adaptive size function.

With these conditions Principal Stress, Equivalent Stress and Deformation was observed in every combination of materials.

2.2.1. Copper – Aluminium – Copper
Fig. 5. Deformation of the Force Plate with Cu-Al-Cu
In Copper - Aluminium - Copper combination, both plates were fabricated with copper alloy and the sensor is made up of Aluminium alloy.
- The maximum principal stress obtained is 3.5669E+5 Pa as shown in figure 3.
- The maximum Equivalent stress obtained is 3.3774E+5 Pa as shown in figure 4.
- The Maximum Deformation is 1.5489E-6 m as shown in figure 5.

2.2.2. Grey Cast Iron – Aluminium – Grey Cast Iron

In Grey Cast Iron - Aluminium – Grey Cast Iron combination, both plates were fabricated with Grey Cast Iron alloy and the sensor is made up of Aluminium alloy.
- The maximum principal stress obtained is 3.5637E+5 Pa as shown in figure 6.
- The maximum Equivalent stress obtained is 3.4193E+5 Pa as shown in figure 7.
- The Maximum Deformation is 1.567E-6 m as shown in figure 8.

2.2.3. Structural Steel – Aluminium – Structural Steel

In Grey Cast Iron - Aluminium – Grey Cast Iron combination, both plates were fabricated with Grey Cast Iron alloy and the sensor is made up of Aluminium alloy.
- The maximum principal stress obtained is 3.5637E+5 Pa as shown in figure 6.
- The maximum Equivalent stress obtained is 3.4193E+5 Pa as shown in figure 7.
- The Maximum Deformation is 1.567E-6 m as shown in figure 8.
In Structural Steel - Aluminium – Structural Steel combination, both plates were fabricated with Structural Steel alloy and the sensor is made up of Aluminium alloy.

- The maximum principal stress obtained is 3.5462E+5 Pa as shown in figure 9.
- The maximum Equivalent stress obtained is 3.4808E+5 Pa as shown in figure 10.
- The Maximum Deformation is 1.5702E-6 m as shown in figure 11.

**2.2.4. Stainless Steel – Aluminium – Stainless Steel**

In Stainless Steel - Aluminium – Stainless Steel combination, both plates were fabricated with Stainless Steel alloy and the sensor is made up of Aluminium alloy.

- The maximum principal stress obtained is 3.5532E+5 Pa as shown in figure 12.
- The maximum Equivalent stress obtained is 3.4706E+5 Pa as shown in figure 13.
- The Maximum Deformation is 9.5029E-7 m as shown in figure 14.

### 2.3. Material Properties

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (kg/m³)</th>
<th>Young's Modulus (Pa)</th>
<th>Poisson's Ratio</th>
<th>Shear Modulus (Pa)</th>
<th>Bulk Modulus (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>2770</td>
<td>7.1E+10</td>
<td>0.33</td>
<td>2.6E+10</td>
<td>6.9E+10</td>
</tr>
<tr>
<td>Copper</td>
<td>8330</td>
<td>1.1E+11</td>
<td>0.34</td>
<td>4.1E+11</td>
<td>1.1E+11</td>
</tr>
<tr>
<td>Grey Cast Iron</td>
<td>7200</td>
<td>1.1E+11</td>
<td>0.28</td>
<td>4.3E+10</td>
<td>8.3E+10</td>
</tr>
<tr>
<td>Structural Steel</td>
<td>7850</td>
<td>2E+11</td>
<td>0.3</td>
<td>7.7E+10</td>
<td>2E+11</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>7750</td>
<td>1.9E+11</td>
<td>0.31</td>
<td>7.4E+10</td>
<td>1.7E+11</td>
</tr>
</tbody>
</table>

### 2.4. Fatigue Analysis

The Fatigue Analysis is used to check the Durability (Life Span), Damage, Factor of Safety of Force plate, where continuous cyclic load is applied.

The above figure 15 shows durability force plate as maximum of E+6.
The above figure 16 represents the damage of force plate maximum at 1000N.

The above figure 17 represents safety factor maximum is 15.

3. Fabrication
The fabrication of force plate was done by considering two stainless steel rods welded into rectangular shape. The softening and buffing operations are performed. The top frame is covered with aluminium sheet to provide convenienee in standing so as to apply the pressure. The aluminium sheet is preferred as it is economically feasible. The dimension of top frame is: 330 mm x 330 mm x 25 mm, and that of the bottom frame is: 380 mm x 380 mm x 25 mm.

4. Result
The bar graph shows the result of material and their properties. Materials Copper, Grey Cast Iron, Structural Steel and Stainless Steel are shown on x-axis and on the y-axis the properties of Principal Stress, Equivalent Stress and Deformation are shown. The bar graph shows maximum Principal Stress on Structural Steel and Equivalent Stress on Stainless Steel.
The above graph shows deformation obtained in each material under some loading conditions.

<table>
<thead>
<tr>
<th>Material</th>
<th>Principal Stress (Pa) (Max)</th>
<th>Equivalent Stress (Pa) (Max)</th>
<th>Deformation (m) (Max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CU-AL-CU</td>
<td>3.57E+05</td>
<td>3.37E+05</td>
<td>1.54E-06</td>
</tr>
<tr>
<td>GEI-AL-GEI</td>
<td>3.56E+05</td>
<td>3.42E+05</td>
<td>1.57E-06</td>
</tr>
<tr>
<td>StS-AL-StS</td>
<td>3.54E+05</td>
<td>3.48E+05</td>
<td>1.57E-06</td>
</tr>
<tr>
<td>SS-AL-SS</td>
<td>3.55E+05</td>
<td>3.47E+05</td>
<td>9.50E-07</td>
</tr>
</tbody>
</table>

5. Conclusion

From the results shown above in the graphs and table, it can be concluded that stainless steel and structural steel materials are suitable for better and efficient working of the Force plate, and the prosthetic manufactures in biomechanics field can get feasible results using these materials.

From the analysis it is observed that:

- Principal Stress is minimum in Stainless Steel - Aluminium - Stainless Steel combination.

- Equivalent Stress is minimum in Copper – Aluminium – Copper combination.

- Deformation is minimum in Stainless Steel – Aluminium - Stainless Steel combination.

On comparing different parameters, it is suggested that using Stainless Steel – Aluminium - Stainless Steel combination as material is preferred.

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References:


