Dynamic Loading Analysis and Redesign for the Hip Joint of the Bipedal Machine

Overview
Current construction machines available on the market are primarily wheel or tread bound. While this allows them to perform heavy lifting tasks effectively on smooth terrain, these machines lose their effectiveness when operating in environments that are not smooth or paved. Colin Darney, owner of Experimental Designs, Inc., has come to this realization and is seeking to design a Bipedal Machine that will combine the current capabilities of construction equipment with human mimicry. This will produce a design that provides a more flexible construction platform for use in both conventional construction tasks and in the relief of disaster situations like hurricanes and earthquakes.

Objectives
The Bipedal Machine is a continuing project among senior design teams at Penn State. This semester, the team was tasked with redesigning the current hip structure so that it would be able to both withstand the dynamic loadings incurred during walking and articulate the appropriate degrees of freedom and ranges of motion required to mimic the human hip.

Approach
The team executed a full design process from initial research and customer needs gathering to testing and evaluation. Throughout this process, the team performed the following:

- Gathered a list of customer needs from the sponsor and from research of the construction industry
- Researched Biomechanics data to determine joint reaction forces in humans while walking and appropriate ranges of motion necessary to mimic the human hip
- Generated a list of engineering specifications from this data
- Performed initial concept generation to create designs that would improve the hip structure
- Performed Finite Element Analysis (FEA) on the current hip structure with ANSYS and iteratively redesigned the SolidWorks model to obtain a hip joint capable of withstanding the dynamic loading conditions
- Added bushings to the hip joint connections to minimize wear of the primary structural components
- Constructed a 1/10-scale prototype of the hip joint for display purposes
- Tested the prototype and the solid model to determine the design’s ability to meet the customer needs

Outcomes
As a result of this redesign process, the team was able to create a hip joint for the Bipedal Machine that is able to:

- Withstand the dynamic loadings placed on the structure during walking with a minimum factor of safety of 1.37 to yielding
- Articulate the hip degrees of freedom with the ranges of motion provided in Table 1.
- Decrease the manufacturing time and cost by being assembled from simple geometric components
- Extend the life of the hip components to operate for 460 hours before replacement of the bushings is necessary
- Increase the team’s confidence that the Bipedal Machine is structurally feasible

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Table 1. Hip Design Ranges of Motion

<table>
<thead>
<tr>
<th>Hip Degree of Freedom</th>
<th>Range of Motion for Current Design</th>
<th>Specified Range of Motion</th>
<th>Percent of Range of Motion Met by Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extension</td>
<td>17.65 degrees</td>
<td>15 degrees</td>
<td>117%</td>
</tr>
<tr>
<td>Flexion</td>
<td>60.56 degrees</td>
<td>140 degrees</td>
<td>43%</td>
</tr>
<tr>
<td>Abduction</td>
<td>30.73 degrees</td>
<td>30 degrees</td>
<td>102%</td>
</tr>
<tr>
<td>Adduction</td>
<td>28.48 degrees</td>
<td>25 degrees</td>
<td>113%</td>
</tr>
<tr>
<td>Medial</td>
<td>360 degrees</td>
<td>70 degrees</td>
<td>514%</td>
</tr>
<tr>
<td>Lateral</td>
<td>360 degrees</td>
<td>90 degrees</td>
<td>400%</td>
</tr>
</tbody>
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