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# Design, Analysis and 3D Printing of Bellows Coupling

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## ABSTRACT:

Bellows couplings combine stainless steel bellows and black anodized aluminum hubs to offer superior performance in motion control applications. The bellows are made of stainless steel, which makes them ideal for transmitting torque. Due to the bellows' thin walls, the coupling is able to flex easily while remaining rigid under torsional loads. Parallel misalignment, angular misalignment and axial motion are accommodated by the bellows coupling. The combination of aluminum hubs with the bellows results in an extremely lightweight, low inertia coupling. Zero backlashes and a long, maintenance-free life are assured since the bellows coupling has no moving parts. An important feature of the bellows coupling is a balanced design to reduce vibration in high rpm applications of up to 10,000 rpm. Bellows couplings are especially suited for high-end servo, stepper, encoder and positioning applications. The present work is directed towards the modeling of Bellows coupling in a 3D CAD tool called SOLIDWORKS .The von misses stresses, resultant deformation, strain and areas below factor of safety has been displayed. The analysis was carrying out using Finite Elements software, Meshing tools simulation tool and Modeling on SOLIDWORKS. This analysis is a partial work of a major project wherein the bellows coupling will be subjected to load by applying three different materials. Rapid Prototyping (RP) can be defined as a group of techniques used to quickly fabricate a scale model of a part or assembly using three-dimensional computer aided design (CAD) data. What is commonly considered to be the first RP technique, Stereo-lithography, was developed by 3D Systems of Valencia, CA, USA. The company was founded in 1986, and since then, a number of different RP techniques have become available. From the results ABS material has induced more stresses i.e., 10.4Mpa than remaining materials stainless steel and plain carbon steel 9.5817Mpa each. But the plain carbon steel has induced less stresses i.e. 9.58165Mpa than its material yield strength of 220Mpa.It has generated less stresses compared to remaining other two materials. Even plain carbon steel material has the less displacement compared to ABS and stainless steel material. Therefore plain carbon steel material is the best suitable material for BELLOWS coupling among the other two materials namely ABS and stainless steel. The Rapid Prototyping of Bellows coupling has been by using FDM machine. The Prototype has been used as pattern for limited volume of production.

## I. INTRODUCTION:

A coupling is a device used to connect two shafts together at their ends for the purpose of transmitting power. Couplings do not normally allow disconnection of shafts during operation, however there are torque limiting couplings which can slip or disconnect when some torque limit is exceeded. The primary purpose of couplings is to join two pieces of rotating equipment while permitting some degree of misalignment or end movement or both.

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By careful selection, installation and maintenance of couplings, substantial savings can be made in reduced maintenance costs and downtime.

## BELLOWS COUPLINGS

A beam coupling, also known as helical coupling, is a flexible coupling for transmitting torque between two shafts while allowing for angular misalignment, parallel offset and even axial motion, of one shaft relative to the other. This design utilizes a single piece of material and becomes flexible by removal of material along a spiral path resulting in a curved flexible beam of helical shape. Since it is made from a single piece of material, the Beam Style coupling does not exhibit the backlash found in some multi-piece couplings. Another advantage of being an all machined coupling is the possibility to incorporate features into the final product while still keeps the single piece integrity.

Fig.1.6.1. Bellows

## I. MODELING OF BELLOWS COUPLING

For the connection of two shafts of 7mm diameter and 12mm diameter respectively Bellows coupling have been modeled. The bellows, clamps of 7mm and 12mm have been modeled and assembled using fasteners.

## MODELING OF BELLOWS

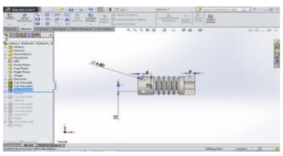

Fig4.1.1. Front view of bellows

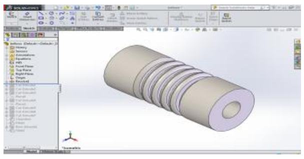

Fig4.1.2. Isometric view of bellows

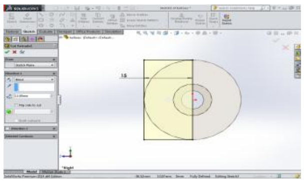

Fig4.1.3. Drawing of bellows

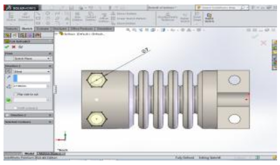

Fig4.1.4. Modeling of bellows front view

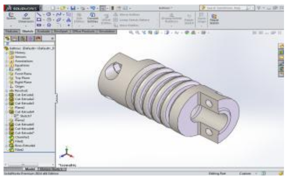

Fig4.1.5. Modeling of bellows isometric view

## MODELING OF 12mm CLAMP

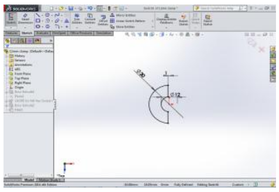

Fig4.2.1. Drawing of 12mm clamp front view

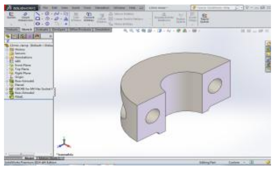

Fig4.2.2. Modeling of 12mm clamp isometric view

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### MODELING OF 7mm CLAMP

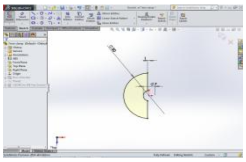


Fig4.3.1. Drawing of 7mm clamp front view

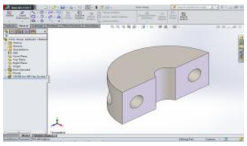


Fig 4.3.2. Modeling of 12mm clamp isometric view

### MODELING OF 7mm SHAFT

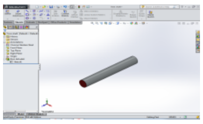


Fig4.4.1. Modeling of 7mm shaft

### MODELING OF 12mm SHAFT

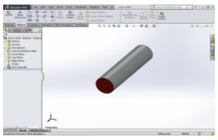


Fig4.5.1. Modeling of 12mm shaft

### ASSEMBLY OF BELLOWS COUPLING WITH SHAFTS

Fig4.6.1. Assembly of bellows coupling with shafts

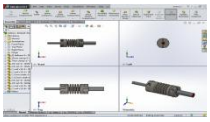


Fig4.6.2. Four views of bellows coupling with shafts Modeling

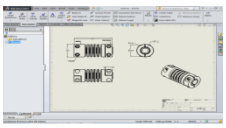


Fig4.6.3. Four views of bellows coupling with shafts drawing

## II. STRUCTURAL AND DYNAMIC ANALYSIS OF BELLOWS COUPLING

The structural analysis of bellows coupling is carried by applying three different materials namely ABS, stainless steel and plain carbon steel to bellows. The loading condition of 20N is applied to the bellows for three materials and will select the best performing material among them.

MATERIAL PROPERTIES

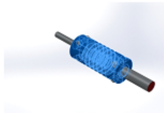
| Model Reference | Properties |
|---|---|
|  | Name: **ABS**<br>Model type: **Linear Elastic Isotropic**<br>Default failure criterion: **Unknown**<br>Tensile strength: **3e+007 N/m^2**<br>Elastic modulus: **2e+009 N/m^2**<br>Poisson's ratio: **0.394**<br>Mass density: **1020 kg/m^3**<br>Shear modulus: **3.189e+008 N/m^2** |

Table 6.1.1.1 Material properties for ABS

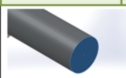
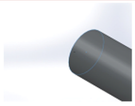
| Fixture name | Fixture Image | Fixture Details |
|---|---|---|
| Fixed-1 |  | Entities: **1 face(s)**<br>Type: **Fixed Geometry** |

Table . 6.1.2.1.Load on the fixed element

| Load name | Load Image | Load Details |
|---|---|---|
| **Force-1** |  | Entities: **1 face(s)**<br>Type: **Apply normal force**<br>Value: **20 N**<br>Phase Angle: **0**<br>Units: **deg** |

6.1.3. MESH INFORMATION

| | |
|---|---|
| Mesh type | Solid Mesh |
| Mesher Used: | Curvature based mesh |
| Jacobian points | 4 Points |
| Maximum element size | 3.24385 mm |
| Minimum element size | 0.648769 mm |
| Mesh Quality | High |
| Remesh failed parts with incompatible mesh | Off |

Mesh Information - Details

| | |
|---|---|
| Total Nodes | 170385 |
| Total Elements | 98898 |
| Maximum Aspect Ratio | 74.311 |
| % of elements with Aspect Ratio < 3 | 86.6 |
| % of elements with Aspect Ratio > 10 | 0.132 |
| % of distorted elements(Jacobian) | 0 |
| Time to complete mesh(hh;mm;ss): | 00:00:18 |
|  | |

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6.2. STRUCTURAL ANALYSIS OF BELLOWS COUPLING BY APPLYING STAINLESS STEEL MATERIAL TO BELLOWS

| | |
|---|---|
| Study name | STATIC2 |
| Analysis type | Static |
| Mesh type | Solid Mesh |
| Thermal Effect: | On |
| Thermal option | Include temperature loads |
| Zero strain temperature | 298 Kelvin |
| Include fluid pressure effects from SolidWorks Flow Simulation | Off |
| Solver type | FFEPlus |
| Inplane Effect: | Off |
| Soft Spring: | Off |
| Inertial Relief: | Off |
| Incompatible bonding options | Automatic |
| Large displacement | On |
| Compute free body forces | On |
| Friction | Off |
| Use Adaptive Method: | Off |
| Result folder | SolidWorks document (E:\Downloads\bellows) |

STUDY RESULTS

| Name | Type | Min | Max |
|---|---|---|---|
| Stress1 | VON: von Mises Stress | 0.000381786 N/mm^2 (MPa) Node: 12534 | 9.5817 N/mm^2 (MPa) Node: 26976 |

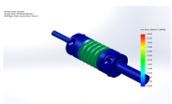


Table.6.2.4.1.Resultant von Misses stress for Stainless steel

| Name | Type | Min | Max |
|---|---|---|---|
| Displacement1 | URES: Resultant Displacement | 0 mm Node: 7392 | 0.00977295 mm Node: 16096 |

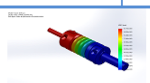


Table.6.2.4.2.Resultant displacement for Stainless steel

## STRUCTURAL ANALYSIS OF BELLOWS COUPLING BY APPLYING PLAIN CARBON STEEL MATERIAL TO BELLOWS

| | |
|---|---|
| Study name | STATIC3 |
| Analysis type | Static |
| Mesh type | Solid Mesh |
| Thermal Effect: | On |
| Thermal option | Include temperature loads |
| Zero strain temperature | 298 Kelvin |
| Include fluid pressure effects from SolidWorks Flow Simulation | Off |
| Solver type | FFEPlus |
| Inplane Effect: | Off |
| Soft Spring: | Off |
| Inertial Relief: | Off |
| Incompatible bonding options | Automatic |
| Large displacement | On |
| Compute free body forces | On |
| Friction | Off |
| Use Adaptive Method: | Off |
| Result folder | SolidWorks document (E:\Downloads\bellows) |

Table.6.3. 1. Structural analysis of bellows coupling by applying plain carbon steel

6.3.1.MATERIAL PROPERTIES

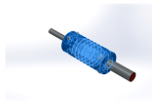
| Model Reference | Properties |
|---|---|
|  | Name: **Plain Carbon Steel**<br>Model type: **Linear Elastic Isotropic**<br>Default failure criterion: **Max von Mises Stress**<br>Yield strength: **2.20594e+008 N/m^2**<br>Tensile strength: **3.99826e+008 N/m^2**<br>Elastic modulus: **2.1e+011 N/m^2**<br>Poisson's ratio: **0.28**<br>Mass density: **7800 kg/m^3** |

Table.6.3.1.1. Material properties for Plain Carbon Steel

6.3.2. LOADS AND FIXTURES

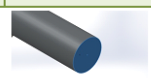
| Fixture name | Fixture Image | Fixture Details |
|---|---|---|
| Fixed-1 |  | Entities: **1 face(s)**<br>Type: **Fixed Geometry** |

Table .6.3.2.1.Load on the fixed element

6.3.4. STUDY RESULTS

| Name | Type | Min | Max |
|---|---|---|---|
| Stress1 | VON: von Mises Stress | 0.000536799 N/mm^2 (MPa) Node: 12534 | 9.58165 N/mm^2 (MPa) Node: 26976 |

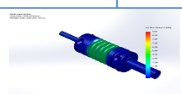


Table.6.3.4.1. von Misses Stress for Plain Carbon steel

| Name | Type | Min | Max |
|---|---|---|---|
| Displacement1 | URES: Resultant Displacement | 0 mm Node: 7392 | 0.00931496 mm Node: 16096 |

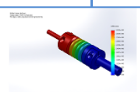


Table.6.3.4.2. Resultant Displacement for Plain Carbon steel

| Name | Type | Min | Max |
|---|---|---|---|
| Strain1 | ESTRN: Equivalent Strain | 2.922e-009 Element: 3879 | 3.22122e-005 Element: 76357 |

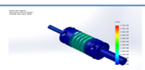


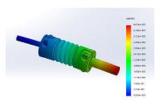
Table.6.3.4.3. Equivalent Strain for Plain Carbon steel

| Name | Type | Min | Max |
|---|---|---|---|
| Factor of Safety1 | Automatic | 23.0225 Node: 26976 | 410943 Node: 12534 |

Table.6.3.4.4.factor of safety for Plain Carbon steel

Study Results

| Name | Type | Min | Max |
|---|---|---|---|
| Amplitude1 | AMPRES: Resultant Amplitude Plot for Mode Shape: 1(Value = 96.2011 Hz) | 0 Node: 6042 | 4.47786 Node: 3482 |



bellows-Frequency 1-Amplitude-Amplitude1

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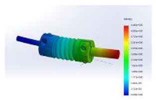
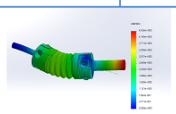
| Name | Type | Min | Max |
|---|---|---|---|
| Amplitude2 | AMPRES: Resultant Amplitude Plot for Mode Shape: 2(Value = 96.4593 Hz) | 0 Node: 6042 | 4.46779 Node: 3759 |



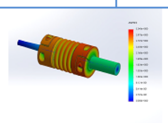
bellows-Frequency 1-Amplitude-Amplitude2

| Name | Type | Min | Max |
|---|---|---|---|
| Amplitude4 | AMPRES: Resultant Amplitude Plot for Mode Shape: 4(Value = 417.128 Hz) | 0 Node: 6042 | 4.52576 Node: 3463 |



bellows-Frequency 1-Amplitude-Amplitude4

| Name | Type | Min | Max |
|---|---|---|---|
| Amplitude5 | AMPRES: Resultant Amplitude Plot for Mode Shape: 5(Value = 669.933 Hz) | 0 Node: 6042 | 3.24832 Node: 31866 |



bellows-Frequency 1-Amplitude-Amplitude5

## III. RESULTS AND DISCUSSIONS

The results are as follows for each bellows coupling with different materials

| S.NO | MATERIAL | VON-Misses Stress( MPa) | Displacement (mm) | Strain |
|---|---|---|---|---|
| 1. | Stainless steel | 9.5817 | 0.00977295 | 3.38231e-005 |
| 2. | Plain carbon steel | 9.58165 | 0.00931496 | 3.22122e-005 |
| 3. | ABS | 10.4669 | 0.994149 | 0.00402789 |

**Table.7.1. Results for different bellows coupling materials**

By comparing the above results the ABS material has induced more stresses i.e., 10.4Mpa than remaining materials stainless steel and plain carbon steel 9.5817Mpa each. But the plain carbon steel has induced less stresses i.e. 9.58165Mpa than its material yield strength of 220Mpa.It has generated less stresses compared to remaining other two materials. Even plain carbon steel material has the less displacement compared to ABS and stainless steel material. Therefore plain carbon steel material is the best suitable material for BELLOWS coupling among the other two materials namely ABS and stainless steel.

RAPID PROTOTYPING OF BELLOWS COUPLING

After the .STL file of BELLOW COUPLING is imported into the fused deposited machine. The 3D printing has been done for 18 hrs.The following prototype has been obtained .The material used is ABS material

**Fig. 8.7.1.Front view of prototype of bellows coupling**

**Fig. 8.7.2.Isometric view of prototype of bellows coupling**

**Fig.8.7.3. Side view of prototype of bellows coupling**

## IV. CONCLUSION:

Bellows couplings combine stainless steel bellows and black anodized aluminum hubs to offer superior performance in motion control applications. The bellows are made of stainless steel, which makes them ideal for transmitting torque. Due to the bellows' thin walls, the coupling is able to flex easily while remaining rigid under torsional loads. Parallel misalignment, angular misalignment and axial motion are accommodated by the bellows coupling. Bellows couplings are especially suited for high-end servo, stepper, encoder and positioning applications. The present work is directed towards the modeling of Bellows coupling in a 3D CAD tool called SOLIDWORKS. The von misses stresses, resultant deformation, strain and areas below factor of safety has been displayed. The analysis was carrying out using Finite Elements software, Meshing tools simulation tool and Modeling on SOLIDWORKS. This analysis is a partial work of a major project wherein the bellows coupling will be subjected to load by applying three different materials. After the analysis, the pattern of the part is obtained using Rapid prototyping machine. This can be used for Machining/ casting of the original part. From the results ABS material has induced more stresses i.e., 10.4Mpa than remaining materials stainless steel and plain carbon steel 9.5817Mpa each. But the plain carbon steel has induced less stresses i.e. 9.58165Mpa than its material yield strength of 220Mpa.It has generated less stresses compared to remaining other two materials. Even plain carbon steel material has the less displacement compared to ABS and stainless steel material. Therefore plain carbon steel material is the best suitable material for BELLOWS coupling among the other two materials namely ABS and stainless steel. The Rapid Prototyping of Bellows coupling has been by using FDM machine. The Prototype has been used as pattern for limited volume of production. This study can be further extended by performing experimentations and developing suitable manufacturing methods, the above study includes only static position of bellows couplling .we further to consider the dynamic analysis of during collision to get better results.

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