CHAPTER 3
MODELING AND ANALYSIS

3.1 BASICS OF MODELING AND ANALYSIS

The main objective of this study was to explore weight and cost reduction opportunities for a production of connecting rod small end bearing. It also was aimed to check feasibility for the new material with respect to existing material by way of comparing analysis result using CAD software. It has entailed performing a detailed load analysis. Therefore, this study is dealing with Modeling and stress analysis of the connecting rod small end bearing.

Nowadays the research is focused on increasing the output of the internal combustion engine and to reduce their weights. Hence bearing housing of the connecting rod big and small end bearings and main bearings are subjected to severe operating conditions. Due to the increase in bearing loads and desire to reduce the dimensions and component masses in modern combustion engines leads to substantial elastic deformations in the connecting rod and main bearings, which alternatively affects the properties of the lubricating fluid and henceforth the performance. In such applications, the conventional assumption of rigid bushing fails to predict the accurate performance of the bearing and hence the combination of hydrodynamic lubrication with the structural analysis i.e. an elasto hydrodynamic analysis must be considered. In recent years, computer technology has rapidly increased, especially in the form of microcomputer and minicomputer workstation networked to powerful mainframe systems. Simultaneously sophisticated computer aided design systems are being developed at a revolutionary pace to support the engineer. Engineering design is being further transformed by the rapid development and proliferation of computer aided engineering, in particular the finite element method.

Hydrodynamic journal bearings are analyzed by using Pro-Mechanica software for Static structural analysis and fluid structure interaction approach in order to find the Von mises stress developed within bearing due to the pressure applied. Journal bearing models are developed for different pressure to study the deformation and elastic behavior of the bearing. Cavitations in the bearing are neglected by setting all negative pressures to
ambient pressures. The results were compared in order to validate the model with the experimental work carried out and good agreements were found. It is observed that structural analysis method provides a useful platform to study the combined effect of hydrodynamics and elastic behavior of the bearing. It is observed that the Von mises stresses of the bearing are significant and should be considered in order to predict accurate performance of the hydrodynamic journal bearings.

**Table 3.1 Mechanical and Physical properties of Bearing Materials**

<table>
<thead>
<tr>
<th>Materials</th>
<th>Density Kg/m³</th>
<th>Poisson Ratio</th>
<th>Young’s Modulus MPa</th>
<th>Co-efficient of Thermal expansion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast Nylon</td>
<td>1150</td>
<td>0.39</td>
<td>32800</td>
<td>9.555-05 /C or /K</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>24.8 W/m-K</td>
</tr>
<tr>
<td>Cast Nylon6</td>
<td></td>
<td></td>
<td></td>
<td>Commercial Name</td>
</tr>
<tr>
<td>Gunmetal</td>
<td>8719</td>
<td>0.33</td>
<td>95100</td>
<td>1.883e-05 /C or /K</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>74.8 W/m-K</td>
</tr>
<tr>
<td>Brass</td>
<td>8490</td>
<td>0.31</td>
<td>112000</td>
<td>1.900e-05 /C or /K</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>115 W/m-K</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CuPb5Sn5Zn5 C83600</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CuZn33Pb2Si C36000</td>
</tr>
</tbody>
</table>


**3.2 IMAGE REPRESENTATION FOR THE STRUCTURAL ANALYSIS**

In this section various images for Brass, Gun metal and Cast Nylon are included. Totally Six different magnitude of Bearing pressure i.e. 10, 20, 30, 35, 40, and 45 MPa were considered while carried out structural analysis in PTC’s software named Pro Mechanica. As mentioned in the design section that there are various bearing materials which have at good strength and capable enough to handle higher magnitude of pressure. While designing the Bush bearing for the small end of connecting for Internal Combustion engine, we have taken pressure value 35 MPa. With reference to this we have also analyzed the Bushing for 40 and 45 MPa bearing pressure. The various images which included in this section gives information about Maximum and Minimum Von Mises stress developed in the Bushing due to the applied bearing load. While carrying out the structural analysis, other operating condition parameters like Lubricants, Speed, Model geometry etc. were kept the same. The basic intention of this analysis is to check new material name Cast Nylon with respect to conventional bearing materials Brass and Gunmetal.
3.3 STATUS REPORT FOR THE BRASS:

DATE 15-09-13
RUN STATUS REPORT

APPLIED LOAD = 35 MPa

MATERIAL = BRASS

Mechanica Structure Version L-01-41: spg
Summary for Design Study "Analysis1_Brass_35MPa"
Fri Nov 15, 2013   19:39:09

Run Settings
Memory allocation for block solver: 128.0

Parallel Processing Status
Parallel task limit for current run: 4
Parallel task limit for current platform: 64
Number of processors detected automatically: 4

Checking the model before creating elements...
These checks take into account the fact that Auto GEM will
automatically create elements in volumes with material
properties, on surfaces with shell properties, and on curves
with beam section properties.
Generate elements automatically.
Checking the model after creating elements...
No errors were found in the model.

Mechanica Structure Model Summary
Principal System of Units: millimeter Newton Second (mmNs)
Length: mm
Force: N
Time: sec
Temperature: C
Model Type: Three Dimensional

Points: 484
Edges: 2309
Faces: 3240
Springs: 0
Masses: 0
Beams: 0
Shells: 0
Solids: 1417
Elements: 1417

-----------------------------------------------

Standard Design Study

Static Analysis "Analysis1_Brass_35MPa":
Convergence Method: Multiple-Pass Adaptive

Plotting Grid: 4

Convergence Loop Log: (19:39:11)

>> Pass 1 <<

Calculating Element Equations (19:39:11)
Total Number of Equations: 1164
Maximum Edge Order: 1
Solving Equations (19:39:12)
Post-Processing Solution (19:39:12)
Calculating Disp and Stress Results (19:39:12)
Checking Convergence (19:39:14)
Elements Not Converged: 1417
Edges Not Converged: 2309
Local Disp/Energy Index: 100.0%
Global RMS Stress Index: 100.0%
Resource Check (19:39:14)
Elapsed Time (sec): 6.03
CPU Time (sec): 5.09
Memory Usage (kb): 188411
Wrk Dir Dsk Usage (kb): 10240

>> Pass 2 <<
Calculating Element Equations (19:39:14)
  Total Number of Equations: 7344
  Maximum Edge Order: 2
Solving Equations (19:39:15)
Post-Processing Solution (19:39:15)
Calculating Disp and Stress Results (19:39:16)
Checking Convergence (19:39:17)
  Elements Not Converged: 562
  Edges Not Converged: 1931
  Local Disp/Energy Index: 100.0%
  Global RMS Stress Index: 25.9%
Resource Check (19:39:17)
Elapsed Time (sec): 9.26
CPU Time (sec): 8.00
Memory Usage (kb): 201951
Wrk Dir Dsk Usage (kb): 10240

>> Pass 3 <<
Calculating Element Equations (19:39:18)
  Total Number of Equations: 22326
  Maximum Edge Order: 3
Solving Equations (19:39:18)
Post-Processing Solution (19:39:20)
Calculating Disp and Stress Results (19:39:21)
Checking Convergence (19:39:23)
  Elements Not Converged: 78
  Edges Not Converged: 865
  Local Disp/Energy Index: 26.8%
Global RMS Stress Index: 10.1%
Resource Check (19:39:23)
Elapsed Time (sec): 15.24
CPU Time (sec): 13.53
Memory Usage (kb): 205295
Wrk Dir Dsk Usage (kb): 25600

>> Pass 4 <<
Calculating Element Equations (19:39:23)
Total Number of Equations: 47925
Maximum Edge Order: 4
Solving Equations (19:39:27)
Post-Processing Solution (19:39:30)
Calculating Disp and Stress Results (19:39:31)
Checking Convergence (19:39:34)
Elements Not Converged: 0
Edges Not Converged: 118
Local Disp/Energy Index: 22.4%
Global RMS Stress Index: 7.8%
Resource Check (19:39:34)
Elapsed Time (sec): 25.96
CPU Time (sec): 26.69
Memory Usage (kb): 213302
Wrk Dir Dsk Usage (kb): 62464

>> Pass 5 <<
Calculating Element Equations (19:39:34)
Total Number of Equations: 72120
Maximum Edge Order: 5
Solving Equations (19:39:44)
Post-Processing Solution (19:39:53)
Calculating Disp and Stress Results (19:39:56)
Checking Convergence (19:39:58)
Elements Not Converged: 0
Edges Not Converged: 10
Local Disp/Energy Index: 16.1%
Global RMS Stress Index: 6.7%
Resource Check (19:39:58)
Elapsed Time (sec): 50.43
CPU Time (sec): 57.36
Memory Usage (kb): 237891
Wrk Dir Dsk Usage (kb): 293888

>> Pass 6 <<
Calculating Element Equations (19:39:59)
Total Number of Equations: 90285
Maximum Edge Order: 6
Solving Equations (19:40:11)
Post-Processing Solution (19:40:25)
Calculating Disp and Stress Results (19:40:29)
Checking Convergence (19:40:31)
Elements Not Converged: 0
Edges Not Converged: 1
Local Disp/Energy Index: 10.0%
Global RMS Stress Index: 3.6%

RMS Stress Error Estimates:
Load Set Stress Error % of Max Prin Str
----------------- --------------- ----------
LoadSet1  1.45e+01       17.0% of 8.50e+01

** Warning: Convergence was not obtained because the maximum
Polynomial order of 6 was reached.

Resource Check (19:40:38)
Elapsed Time (sec): 89.81
CPU Time (sec): 107.81
Memory Usage (kb): 245604
Wrk Dir Dsk Usage (kb): 408576

The analysis did not converge to within 10% on edge displacement, element strain energy, and global RMS stress.

Total Mass of Model: 1.207939e-04

Mass Moments of Inertia about WCS Origin:
Ixx: 1.09813e-01
Ixy: -2.59127e-10  Iyy: 3.32506e-02
Ixz: -8.25158e-10  Iyz: -1.19326e-09  Izz: 1.10382e-01

Principal MMOI and Principal Axes Relative to WCS Origin:

<table>
<thead>
<tr>
<th>Max Prin</th>
<th>Mid Prin</th>
<th>Min Prin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.10382e-01</td>
<td>1.09813e-01</td>
<td>3.32506e-02</td>
</tr>
</tbody>
</table>
WCS X: -1.45039e-06  1.00000e+00  3.38450e-09
WCS Y: -1.54705e-08 -3.38452e-09  1.00000e+00
WCS Z: 1.00000e+00  1.45039e-06  1.54705e-08

Center of Mass Location Relative to WCS Origin:
(-8.07685e-09, 2.40000e+01, 6.70833e-07)

Mass Moments of Inertia about the Center of Mass:
Ixx: 4.02356e-02
Ixy: -2.82542e-10  Iyy: 3.32506e-02
Ixz: -8.25158e-10  Iyz: 7.51524e-10  Izz: 4.08045e-02
Principal MMOI and Principal Axes Relative to COM:

<table>
<thead>
<tr>
<th>Max Prin</th>
<th>Mid Prin</th>
<th>Min Prin</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.08045e-02</td>
<td>4.02356e-02</td>
<td>3.32506e-02</td>
</tr>
</tbody>
</table>

WCS X: -1.45039e-06 1.00000e+00 4.04501e-08
WCS Y: 9.94884e-08 -4.04500e-08 1.00000e+00
WCS Z: 1.00000e+00 1.45039e-06 -9.94883e-08

Constraint Set: ConstraintSet1: PRT0001
Load Set: LoadSet1: PRT0001
Resultant Load on Model:
in global X direction: -4.82594e-03
in global Y direction: 1.563194e-13
in global Z direction: 7.328903e-02

Measures:

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>Convergence</th>
</tr>
</thead>
<tbody>
<tr>
<td>max_beam_bending:</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_beam_tensile:</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_beam_torsion:</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_beam_total:</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_disp_mag:</td>
<td>9.595535e-04</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_disp_x:</td>
<td>-8.091684e-04</td>
<td>0.9%</td>
</tr>
<tr>
<td>max_disp_y:</td>
<td>4.654923e-04</td>
<td>0.7%</td>
</tr>
<tr>
<td>max_disp_z:</td>
<td>-8.651058e-04</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_prin_mag:</td>
<td>-8.500614e+01</td>
<td>12.6%</td>
</tr>
<tr>
<td>max_rot_mag:</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_rot_x:</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_rot_y:</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_rot_z:</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_stress_prin:</td>
<td>3.598605e+01</td>
<td>7.4%</td>
</tr>
</tbody>
</table>
max_stress_vm:        6.302219e+01      2.4%
max_stress_xx:       -7.518082e+01     14.9%
max_stress_xy:       3.111562e+01       2.1%
max_stress_xz:       -1.987551e+01     10.4%
max_stress_yy:       -3.631504e+01     15.9%
max_stress_yz:        2.276236e+01      4.2%
max_stress_zz:       -7.202290e+01     9.5%
min_stress_prin:     -8.500614e+01      12.6%
strain_energy:        5.278749e+01       0.1%

Analysis "Analysis1_Brass_35MPa" Completed (19:40:38)
--------------------------------------------------- ---------
Memory and Disk Usage:
    Machine Type: Windows NT/x86
    RAM Allocation for Solver (megabytes): 128.0
    Total Elapsed Time (seconds): 90.25
    Total CPU Time     (seconds): 108.16
    Maximum Memory Usage (kilobytes): 245604
    Working Directory Disk Usage (kilobytes): 408576
    Results Directory Size (kilobytes):
        22890 \Analysis1_Brass_35MPa
    Maximum Data Base Working File Sizes (kilobytes):
        253952 \Analysis1_Brass_35MPa.tmp\kblk1.bas
        137216 \Analysis1_Brass_35MPa.tmp\kel1.bas
        17408 \Analysis1_Brass_35MPa.tmp\oel1.bas

------------------------------------------------------------
Run Completed
Sun Sep 15, 2013   19:40:38
------------------------------------------------------------
3.4 STATUS REPORT FOR THE GUNMETAL

MATERIAL = GUNMETAL

Mechanica Structure Version L-01-41:spg

Summary for Design Study "Analysis1_Gunmetal_35MPa"

Sun Sep 15, 2013  19:48:18

Run Settings
Memory allocation for block solver: 128.0

Parallel Processing Status
Parallel task limit for current run: 4
Parallel task limit for current platform: 64
Number of processors detected automatically: 4

Checking the model before creating elements...
These checks take into account the fact that Auto GEM will automatically create elements in volumes with material properties, on surfaces with shell properties, and on curves with beam section properties.

Generate elements automatically.
Checking the model after creating elements...
No errors were found in the model.

Mechanica Structure Model Summary
Principal System of Units: millimeter Newton Second (mmNs)
Length: mm
Force: N
Time: sec
Temperature: °C
Model Type: Three Dimensional
Points: 484
Edges: 2309
Faces: 3240
Springs: 0
Masses: 0
Beams: 0
Shells: 0
Solids: 1417
Elements: 1417
------------------------------------------------------------
Standard Design Study

Static Analysis "Analysis1_Gunmetal_35MPa":
Convergence Method: Multiple-Pass Adaptive
Plotting Grid: 4
Convergence Loop Log: (19:48:21)

>> Pass 1 <<
Calculating Element Equations (19:48:21)
Total Number of Equations: 1164
Maximum Edge Order: 1
Solving Equations (19:48:22)
Post-Processing Solution (19:48:22)
Calculating Disp and Stress Results (19:48:22)
Checking Convergence (19:48:24)
Elements Not Converged: 1417
Edges Not Converged: 2309
Local Disp/Energy Index: 100.0%
Global RMS Stress Index: 100.0%
Resource Check (19:48:24)
Elapsed Time (sec): 6.22
CPU Time (sec): 5.55
Memory Usage (kb): 188411
Wrk Dir Dsk Usage (kb): 10240

>> Pass 2 <<
Calculating Element Equations (19:48:24)
Total Number of Equations: 7344
Maximum Edge Order: 2
Solving Equations (19:48:24)
Post-Processing Solution (19:48:26)
Calculating Disp and Stress Results (19:48:27)
Checking Convergence (19:48:28)
Elements Not Converged: 561
Edges Not Converged: 1948
Local Disp/Energy Index: 100.0%
Global RMS Stress Index: 26.6%
Resource Check (19:48:28)
Elapsed Time (sec): 10.21
CPU Time (sec): 8.11
Memory Usage (kb): 201951
Wrk Dir Dsk Usage (kb): 10240

>> Pass 3 <<
Calculating Element Equations (19:48:28)
Total Number of Equations: 22401
Maximum Edge Order: 3
Solving Equations (19:48:29)
Post-Processing Solution (19:48:31)
Calculating Disp and Stress Results (19:48:32)
Checking Convergence (19:48:34)
Elements Not Converged: 90
Edges Not Converged: 862
Local Disp/Energy Index: 26.9%
Global RMS Stress Index: 10.6%
Resource Check (19:48:35)
Elapsed Time (sec): 16.93
CPU Time (sec): 14.45
Memory Usage (kb): 205307
Wrk Dir Dsk Usage (kb): 26624

>> Pass 4 <<
Calculating Element Equations (19:48:35)
Total Number of Equations: 48015
Maximum Edge Order: 4
Solving Equations (19:48:38)
Post-Processing Solution (19:48:41)
Calculating Disp and Stress Results (19:48:43)
Checking Convergence (19:48:45)
Elements Not Converged: 1
Edges Not Converged: 110
Local Disp/Energy Index: 22.3%
Global RMS Stress Index: 8.0%
Resource Check (19:48:46)
Elapsed Time (sec): 27.99
CPU Time (sec): 27.88
Memory Usage (kb): 213333
Wrk Dir Dsk Usage (kb): 63488

>> Pass 5 <<
Calculating Element Equations (19:48:46)
Total Number of Equations: 72438
Maximum Edge Order: 5
Solving Equations (19:48:54)
Post-Processing Solution (19:49:04)
Calculating Disp and Stress Results (19:49:07)
Checking Convergence (19:49:10)
   Elements Not Converged: 0
   Edges Not Converged: 10
   Local Disp/Energy Index: 16.3%
   Global RMS Stress Index: 7.0%
Resource Check (19:49:11)
   Elapsed Time (sec): 53.17
   CPU Time (sec): 60.09
   Memory Usage (kb): 237911
   Wrk Dir Dsk Usage (kb): 292864

>> Pass 6 <<
Calculating Element Equations (19:49:11)
   Total Number of Equations: 92067
   Maximum Edge Order: 6
Solving Equations (19:49:24)
Post-Processing Solution (19:49:38)
Calculating Disp and Stress Results (19:49:42)
Checking Convergence (19:49:45)
   Elements Not Converged: 0
   Edges Not Converged: 3
   Local Disp/Energy Index: 10.3%
   Global RMS Stress Index: 4.0%
RMS Stress Error Estimates:

<table>
<thead>
<tr>
<th>Load Set</th>
<th>Stress Error</th>
<th>% of Max Prin Str</th>
</tr>
</thead>
<tbody>
<tr>
<td>LoadSet1</td>
<td>1.45e+01</td>
<td>15.4% of 9.43e+01</td>
</tr>
</tbody>
</table>

** Warning: Convergence was not obtained because the maximum polynomial order of 6 was reached.**

Resource Check (19:49:52)

- Elapsed Time (sec): 93.97
- CPU Time (sec): 109.47
- Memory Usage (kb): 245824
- Wrk Dir Dsk Usage (kb): 415744

The analysis did not converge to within 10% on edge displacement, element strain energy, and global RMS stress.

Total Mass of Model: 1.240521e-04

Mass Moments of Inertia about WCS Origin:

- Ixx: 1.12775e-01
- Ixy: -2.66116e-10 Iyy: 3.41475e-02
- Ixz: -8.47415e-10 Iyz: -1.22544e-09 Izz: 1.13359e-01

Principal MMOI and Principal Axes Relative to WCS Origin:

<table>
<thead>
<tr>
<th>Max Prin</th>
<th>Mid Prin</th>
<th>Min Prin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.13359e-01</td>
<td>1.12775e-01</td>
<td>3.41475e-02</td>
</tr>
</tbody>
</table>

WCS X: -1.45039e-06 1.00000e+00 3.38450e-09
WCS Y: -1.54705e-08 -3.38452e-09 1.00000e+00
WCS Z: 1.00000e+00 1.45039e-06 1.54705e-08

Center of Mass Location Relative to WCS Origin:

(-8.07685e-09, 2.40000e+01, 6.70833e-07)

Mass Moments of Inertia about the Center of Mass:

- Ixx: 4.13209e-02
- Ixy: -2.90163e-10 Iyy: 3.41475e-02
- Ixz: -8.47415e-10 Iyz: 7.71795e-10 Izz: 4.19051e-02
Principal MMOI and Principal Axes Relative to COM:

<table>
<thead>
<tr>
<th>Max Prin</th>
<th>Mid Prin</th>
<th>Min Prin</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.19051e-02</td>
<td>4.13209e-02</td>
<td>3.41475e-02</td>
</tr>
</tbody>
</table>

WCS X: -1.45039e-06 1.00000e+00 4.04501e-08
WCS Y: 9.94884e-08 -4.04500e-08 1.00000e+00
WCS Z: 1.00000e+00 1.45039e-06 -9.94883e-08

Constraint Set: ConstraintSet1: PRT0001
Load Set: LoadSet1: PRT0001

Resultant Load on Model:
- in global X direction: -1.052912e-03
- in global Y direction: 6.536993e-12
- in global Z direction: 8.178901e-02

Measures:

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>Convergence</th>
</tr>
</thead>
<tbody>
<tr>
<td>max_beam_bending</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_beam_tensile</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_beam_torsion</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_beam_total</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_disp_mag</td>
<td>1.144202e-03</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_disp_x</td>
<td>-9.272047e-04</td>
<td>0.5%</td>
</tr>
<tr>
<td>max_disp_y</td>
<td>6.099713e-04</td>
<td>0.1%</td>
</tr>
<tr>
<td>max_disp_z</td>
<td>-9.985819e-04</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_prin_mag</td>
<td>-9.425110e+01</td>
<td>16.2%</td>
</tr>
<tr>
<td>max_rot_mag</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_rot_x</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_rot_y</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_rot_z</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
</tbody>
</table>
max_stress_prin: 3.620355e+01 8.0%
max_stress_vm: 5.551982e+01 7.2%
max_stress_xx: -8.089057e+01 13.7%
max_stress_xy: -2.314024e+01 0.2%
max_stress_xz: -1.968340e+01 12.0%
max_stress_yy: -4.263356e+01 18.5%
max_stress_yz: 2.321307e+01 4.4%
max_stress_zz: -7.549497e+01 9.4%
min_stress_prin: -9.425110e+01 16.2%
strain_energy: 5.942868e+01 0.1%

Analysis "Analysis1_Gunmetal_35MPa" Completed (19:49:52)

Memory and Disk Usage:
Machine Type: Windows NT/x86
RAM Allocation for Solver (megabytes): 128.0
Total Elapsed Time (seconds): 94.50
Total CPU Time (seconds): 109.88
Maximum Memory Usage (kilobytes): 245824
Working Directory Disk Usage (kilobytes): 415744
Results Directory Size (kilobytes):
23095 Analysis1_Gunmetal_35MPa
Maximum Data Base Working File Sizes (kilobytes):
256000 Analysis1_Gunmetal_35MPa.tmp\blk1.bas
141312 Analysis1_Gunmetal_35MPa.tmp\el1.bas
18432 Analysis1_Gunmetal_35MPa.tmp\el1.bas

Run Completed
Sun Sep 15, 2013 19:49:52


3.5 STATUS REPORT FOR THE CAST NYLON

MATERIAL = CAST NYLON

------------------------------------------------------------
Mechanica Structure Version L-01-41: spg
Summary for Design Study "Analysis1_CASTNYLON_37_5MPa"
Sun Sep 15, 2013  19:53:00
------------------------------------------------------------

Run Settings
Memory allocation for block solver: 128.0

Parallel Processing Status
Parallel task limit for current run: 4
Parallel task limit for current platform: 64
Number of processors detected automatically: 4
Checking the model before creating elements...
These checks take into account the fact that Auto GEM will automatically create elements in volumes with material properties, on surfaces with shell properties, and on curves with beam section properties.

Generate elements automatically.
Checking the model after creating elements...
No errors were found in the model.
Mechanica Structure Model Summary
Principal System of Units: millimeter Newton Second (mmNs)
Length: mm
Force: N
Time: sec
Temperature: C
Model Type: Three Dimensional

Points: 484
Edges: 2309
Faces: 3240
Springs: 0
Masses: 0
Beams: 0
Shells: 0
Solids: 1417
Elements: 1417

-----------------------------------

Standard Design Study

Static Analysis "Analysis1_CASTNYLON_35MPa":

Convergence Method: Multiple-Pass Adaptive
Plotting Grid: 4
Convergence Loop Log: (19:53:02)

>> Pass 1 <<
Calculating Element Equations (19:53:03)
Total Number of Equations: 1164
Maximum Edge Order: 1
Solving Equations (19:53:03)
Post-Processing Solution (19:53:03)
Calculating Disp and Stress Results (19:53:03)
Checking Convergence (19:53:04)
Elements Not Converged: 1417
Edges Not Converged: 2309
Local Disp/Energy Index: 100.0%
Global RMS Stress Index: 100.0%
Resource Check (19:53:05)
Elapsed Time (sec): 5.01
CPU Time (sec): 4.50
Memory Usage (kb): 188411
Wrk Dir Dsk Usage (kb): 10240

>> Pass 2 <<
Calculating Element Equations (19:53:05)
Total Number of Equations: 7344
Maximum Edge Order: 2
Solving Equations (19:53:05)
Post-Processing Solution (19:53:06)
Calculating Disp and Stress Results (19:53:06)
Checking Convergence (19:53:07)
Elements Not Converged: 638
Edges Not Converged: 1992
Local Disp/Energy Index: 100.0%
Global RMS Stress Index: 31.9%
Resource Check (19:53:08)
Elapsed Time (sec): 8.13
CPU Time (sec): 6.66
Memory Usage (kb): 201951
Wrk Dir Dsk Usage (kb): 10240

>> Pass 3 <<
Calculating Element Equations (19:53:08)
Total Number of Equations: 22566
Maximum Edge Order: 4
Solving Equations (19:53:09)
Post-Processing Solution (19:53:10)
Calculating Disp and Stress Results (19:53:11)
Checking Convergence (19:53:13)
Elements Not Converged: 136
Edges Not Converged: 994
Local Disp/Energy Index: 28.9%
Global RMS Stress Index: 13.8%
Resource Check 19:53:13
Elapsed Time (sec): 13.23
CPU Time (sec): 11.59
Memory Usage (kb): 206339
Wrk Dir Dsk Usage (kb): 26624

>> Pass 4 <<
Calculating Element Equations (19:53:13)
Total Number of Equations: 48921
Maximum Edge Order: 4
Solving Equations (19:53:17)
Post-Processing Solution (19:53:20)
Calculating Disp and Stress Results (19:53:22)
Checking Convergence (19:53:24)
Elements Not Converged: 6
Edges Not Converged: 139
Local Disp/Energy Index: 21.6%
Global RMS Stress Index: 10.2%
Resource Check (19:53:24)
Elapsed Time (sec): 24.90
CPU Time (sec): 25.02
Memory Usage (kb): 214262
Wrk Dir Dsk Usage (kb): 64512

>> Pass 5 <<
Calculating Element Equations (19:53:25)
Total Number of Equations: 79044
Maximum Edge Order: 5
Solving Equations (19:53:33)
Post-Processing Solution (19:53:44)
Calculating Disp and Stress Results (19:53:47)
Checking Convergence (19:53:49)
  Elements Not Converged: 0
  Edges Not Converged: 18
  Local Disp/Energy Index: 16.4%
  Global RMS Stress Index: 9.0%

Resource Check (19:53:50)
  Elapsed Time (sec): 50.57
  CPU Time (sec): 59.42
  Memory Usage (kb): 238677
  Wrk Dir Dsk Usage (kb): 337920

>> Pass 6 <<
Calculating Element Equations (19:53:50)
  Total Number of Equations: 107670
  Maximum Edge Order: 6
Solving Equations 19:54:07)
Post-Processing Solution (19:54:25)
Calculating Disp and Stress Results (19:54:31)
Checking Convergence (19:54:33)
  Elements Not Converged: 0
  Edges Not Converged: 5
  Local Disp/Energy Index: 11.2%
  Global RMS Stress Index: 6.4%

RMS Stress Error Estimates:

<table>
<thead>
<tr>
<th>Load Set</th>
<th>Stress Error</th>
<th>% of Max Prin Str</th>
</tr>
</thead>
<tbody>
<tr>
<td>LoadSet1</td>
<td>1.52e+01</td>
<td>12.4% of 1.23e+02</td>
</tr>
</tbody>
</table>

** Warning: Convergence was not obtained because the maximum polynomial order of 6 was reached.**
The analysis did not converge to within 10% on edge displacement, element strain energy, and global RMS stress.

Total Mass of Model: 1.707532e-05

Mass Moments of Inertia about WCS Origin:

\begin{align*}
I_{xx} &= 1.55230e-02 \\
I_{xy} &= -3.66299e-11, I_{yy} = 4.70028e-03 \\
I_{xz} &= -1.16644e-10, I_{yz} = -1.68678e-10, I_{zz} = 1.56035e-02
\end{align*}

Principal MMOI and Principal Axes Relative to WCS Origin:

\begin{align*}
\text{Max Prin} & \quad \text{Mid Prin} & \quad \text{Min Prin} \\
I_{xx} &= 1.56035e-02 & I_{yy} &= 1.55230e-02 & I_{zz} &= 4.70028e-03 \\
WCS X: & -1.45039e-06 & 1.00000e+00 & 3.38450e-09 \\
WCS Y: & -1.54705e-08 & -3.38452e-09 & 1.00000e+00 \\
WCS Z: & 1.00000e+00 & 1.45039e-06 & 1.54705e-08
\end{align*}

Center of Mass Location Relative to WCS Origin:
\((-8.07685e-09, 2.40000e+01, 6.70833e-07)\)

Mass Moments of Inertia about the Center of Mass:

\begin{align*}
I_{xx} &= 5.68767e-03 \\
I_{xy} &= -3.99398e-11, I_{yy} = 4.70028e-03 \\
I_{xz} &= -1.16644e-10, I_{yz} = 1.06235e-10, I_{zz} = 5.76809e-03
\end{align*}
Principal MMOI and Principal Axes Relative to COM:

<table>
<thead>
<tr>
<th></th>
<th>Max Prin</th>
<th>Mid Prin</th>
<th>Min Prin</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5.76809e-03</td>
<td>5.68767e-03</td>
<td>4.70028e-03</td>
</tr>
</tbody>
</table>

WCS X: -1.45039e-06 1.00000e+00 4.04501e-08
WCS Y: 9.94884e-08 -4.04500e-08 1.00000e+00
WCS Z: 1.00000e+00 1.45039e-06 -9.94883e-08

Constraint Set: ConstraintSet1: PRT0001
Load Set: LoadSet1: PRT0001
Resultant Load on Model:
in global X direction: -1.183777e-03
in global Y direction: 3.765876e-12
in global Z direction: -1.251931e-02

Measures:

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>Convergence</th>
</tr>
</thead>
<tbody>
<tr>
<td>max_beam_bending</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_beam_tensile</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_beam_torsion</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_beam_total</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_disp_mag</td>
<td>2.960913e-02</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_disp_x</td>
<td>-2.051247e-02</td>
<td>0.8%</td>
</tr>
<tr>
<td>max_disp_y</td>
<td>2.086032e-02</td>
<td>0.1%</td>
</tr>
<tr>
<td>max_disp_z</td>
<td>2.230051e-02</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_prin_mag</td>
<td>-1.227131e+02</td>
<td>11.9%</td>
</tr>
<tr>
<td>max_rot_mag</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_rot_x</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_rot_y</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_rot_z</td>
<td>0.000000e+00</td>
<td>0.0%</td>
</tr>
<tr>
<td>max_stress_prin</td>
<td>5.613777e+01</td>
<td>9.8%</td>
</tr>
<tr>
<td>max_stress_vm</td>
<td>6.567895e+01</td>
<td>7.7%</td>
</tr>
</tbody>
</table>
max_stress_xx:  -1.092708e+02        15.1%
max_stress_xy:  3.161855e+01         5.3%
max_stress_xz:  -1.675816e+01         0.3%
max_stress_yy:  -6.706988e+01        13.5%
max_stress_yz:  -2.747842e+01         2.5%
max_stress_zz:  -8.058130e+01        14.8%
min_stress_prin:  -1.227131e+02        11.9%
strain_energy:  1.104414e+03         0.2%

Analysis "Analysis1_CASTNYLON_35MPa" Completed (19:54:42)

Memory and Disk Usage:
Machine Type: Windows NT/x86
RAM Allocation for Solver (megabytes): 128.0
Total Elapsed Time (seconds): 102.20
Total CPU Time     (seconds): 125.55
Maximum Memory Usage (kilobytes): 249591
Working Directory Disk Usage (kilobytes): 536576
Results Directory Size (kilobytes):
  24871 .\Analysis1_CASTNYLON_35MPa
Maximum Data Base Working File Sizes (kilobytes):
  338944 .\Analysis1_CASTNYLON_35MPa.tmp\kblk1.bas
  176128 .\Analysis1_CASTNYLON_35MPa.tmp\kel1.bas
  21504 .\Analysis1_CASTNYLON_35MPa.tmp\oel1.bas

Run Completed
Sun Sep 15, 2013   19:54:42
3.6 DISCUSSION ON THE STATUS REPORT

When the FEM is applied to a specific field of analysis (like stress analysis, vibration analysis or thermal analysis) it is often referred to as finite element analysis (FEA). An FEA is the most common tool for stress and structural analysis. Various fields of study are often correlated to each other. For example, distributions of non-uniform temperatures in FEA model induce non-obvious loading conditions on solid structural members. Thus, it is common to conduct a thermal FEA to obtain temperature results that in turn become input data for a stress FEA. The basic concept behind the FEA is to replace any complex shape with the union (or summation) of a large number of very simple shapes (like triangles) that are combined to correctly model for the original part. The smaller simpler shapes are known as finite elements because each one occupies a small but finite sub-domain of the solid model. They contrast to the infinitesimally small or differential elements used for centuries to derive differential equations. FEA can also receive input data from other tools like motion (kinetics) analysis systems and computation fluid dynamics systems.

When we use any standard CAD/CAM software, normally we do not get many details about what is happening inside while software is running. Here in our case we used Pro Mechanica software for structural analysis. In status report we can have detailed information about solid model like number of elements used to discretize the bush bearing solid model, points, edges etc. If we refer status report we can have how much time consumed by CPU (Central processing unit) and memory utilized to store the results. To have more precise result we have opted to work out analysis in six pass instead of quick pass. Status report also include magnitude for principle stress in all directions, magnitude for strain energy, displacement in x, y and z directions etc. For all three materials at pressure 35 MPa, the status report are shown above for the reference purpose. The status report would help us to understand bit function of Pro Mechanica software.
3.7 PHOTOGRAPHIC IMAGE REPRESENTATION FOR BRASS

Figure: 3.1 Von Mises stress For Brass (10 MPa)

Figure: 3.2 Von Mises stress For Brass (20 MPa)
Figure: 3.3 Von Mises stress For Brass (30 MPa)

Figure: 3.4 Von Mises stress For Brass (35 MPa)
Figure: 3.5 Von Mises stress For Brass (40 MPa)

Figure: 3.6 Von Mises stress For Brass (45 MPa)
3.8 PHOTOGRAPHIC IMAGE REPRESENTATION FOR GUNMETAL

Figure: 3.7 VonMises stress For Gunmetal (10 MPa)

Figure: 3.8 VonMises stress For Gunmetal (20 MPa)
Figure: 3.9 VonMises stress For Gunmetal (30 MPa)

Figure: 3.10 VonMises stress For Gunmetal (35 MPa)
Figure: 3.11 VonMises stress For Gunmetal (40 MPa)

Figure: 3.12 VonMises stress For Gunmetal (45 MPa)
3.9 PHOTOGRAPHIC IMAGE REPRESENTATION FOR CAST NYLON

Figure: 3.13 VonMises stress For Cast Nylon (10 MPa)

Figure: 3.14 VonMises stress For Cast Nylon (20 MPa)
Figure: 3.15 VonMises stress For Cast Nylon (30 MPa)

Figure: 3.16 VonMises stress For Cast Nylon (35 MPa)
Figure: 3.17 VonMises stress For Cast Nylon (40 MPa)

Figure: 3.18 VonMises stress For Cast Nylon (45 MPa)
3.10 ANALYSIS SUMMARY FOR BEARING MATERIALS

The static structural analysis was carried out using Pro Mechanica software for the Brass, Gunmetal and Cast Nylon and Von Misses stresses (Maximum and Minimum) were recorded in tabular form. The entire analysis summary report is represented in the Table 3.1 (Maximum) and Table 3.2 (Minimum) Von Mises stress.

Table No. 3.2 Readings for applied pressure and Von Mises stress (Maximum)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>8.403E+00</td>
<td>8.403</td>
<td>7.403E+00</td>
<td>7.403</td>
<td>8.757E+00</td>
<td>8.757</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>1.437E+01</td>
<td>14.37</td>
<td>1.481E+01</td>
<td>14.81</td>
<td>1.751E+01</td>
<td>17.51</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>2.874E+01</td>
<td>28.74</td>
<td>2.961E+01</td>
<td>29.61</td>
<td>3.503E+01</td>
<td>35.03</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
<td>5.042E+01</td>
<td>50.42</td>
<td>4.442E+01</td>
<td>44.42</td>
<td>4.857E+01</td>
<td>48.57</td>
</tr>
<tr>
<td>5</td>
<td>35</td>
<td>5.882E+01</td>
<td>58.82</td>
<td>8.182E+01</td>
<td>51.82</td>
<td>6.130E+01</td>
<td>61.3</td>
</tr>
<tr>
<td>6</td>
<td>40</td>
<td>6.722E+01</td>
<td>67.22</td>
<td>5.922E+01</td>
<td>59.22</td>
<td>7.006E+01</td>
<td>70.06</td>
</tr>
<tr>
<td>7</td>
<td>45</td>
<td>7.563E+01</td>
<td>75.63</td>
<td>6.682E+01</td>
<td>66.62</td>
<td>7.285E+01</td>
<td>72.85</td>
</tr>
<tr>
<td>8</td>
<td>50</td>
<td>1.086E+02</td>
<td>108.6</td>
<td>7.403E+01</td>
<td>74.03</td>
<td>8.757E+01</td>
<td>87.57</td>
</tr>
</tbody>
</table>

Figure: 3.19 Bearing Pressure Vs. Von Mises Stresses (Maximum)
Table No. 3.3 Readings for applied pressure and Von Mises stress (Minimum)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>1.183E-01</td>
<td>0.1183</td>
<td>2.242E-01</td>
<td>0.2242</td>
<td>2.251E-01</td>
<td>0.2251</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>2.671E-01</td>
<td>0.2671</td>
<td>4.483E-01</td>
<td>0.4483</td>
<td>4.503E-01</td>
<td>0.4503</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>5.341E-01</td>
<td>0.5341</td>
<td>8.967E-01</td>
<td>0.8967</td>
<td>9.006E-01</td>
<td>0.9006</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
<td>7.099E-01</td>
<td>0.7099</td>
<td>1.345E+00</td>
<td>1.345</td>
<td>1.545E+00</td>
<td>1.545</td>
</tr>
<tr>
<td>5</td>
<td>35</td>
<td>8.282E-01</td>
<td>0.8282</td>
<td>1.569E+00</td>
<td>1.569</td>
<td>1.576E+00</td>
<td>1.576</td>
</tr>
<tr>
<td>6</td>
<td>40</td>
<td>9.465E-01</td>
<td>0.9465</td>
<td>1.703E+00</td>
<td>1.703</td>
<td>1.801E+00</td>
<td>1.801</td>
</tr>
<tr>
<td>7</td>
<td>45</td>
<td>1.065E+00</td>
<td>1.065</td>
<td>2.018E+00</td>
<td>2.018</td>
<td>2.317E+00</td>
<td>2.317</td>
</tr>
<tr>
<td>8</td>
<td>50</td>
<td>1.250E+00</td>
<td>1.25</td>
<td>2.242E+00</td>
<td>2.242</td>
<td>2.251E+00</td>
<td>2.251</td>
</tr>
</tbody>
</table>

Figure: 3.20 Bearing Pressure Vs. Von Mises Stresses (Minimum)
3.11 STRUCTURAL ANALYSIS AND DISCUSSION

Few bearing material physical properties have a direct relationship with compressive strength, fatigue strength, embed ability and conformability. Compressive strength is a basic requirement for the bearing material to support bearing load without extruding or cracking.

As mentioned earlier for the structural analysis, Pro-Mechanica software was used. In the result window Maximum and Minimum value of Von Mises stress for the Bushing Model were located and its BMP images stored for different pressure. Considering the technical specification and available technical data from the manufacturer, we found that at top dead center when fuel ignition take place inside the piston chamber, the maximum gas pressure developed due to the ignition of fuel was 4.95 N/mm\(^2\) and force acting upon piston due to the ignition of fuel was found 507700 Newton ( Rounded). In the structural analysis at 35 MPa Bearing pressure the value of Von Mises stress for the proposed new material Cast Nylon was 61.3 N/mm\(^2\) which is quite safe considering its compressive strength 115 N/mm\(^2\). Of course at this bearing pressure i.e. at 35 N/mm\(^2\), the maximum Von Mises stress for the Brass is 58.82 N/mm\(^2\) and for the Gunmetal it is 51.82 N/mm\(^2\) (Refer Table 3.2). The Maximum and Minimum Von Mises Stress versus Bearing pressure applied is graphically represented in the figure 3.19 and figure 3.20 . We can conclude that if we replace the conventional bush bearing made from brass or gunmetal by a new material named Cast Nylon, there will not be any problem related to the stress developed due to the Gas force through piston and connecting rod assemblies.