Magneto-rheological Fluid Knee (MRF Knee)

Mechanical Engineering

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Introduction

There is a market value for a new and improved prosthetic knee using magneto-rheological fluid (MRF or MR fluid) to create a natural resistive braking torque during motion of the prosthetic. Current generation commercially available prosthetic knee systems are very inefficient; none of them can perfectly match the movement of the leg with a natural knee. Additionally, all current generation models that can closely mimic a patient's gait well, such as the Rheo Knee 3 and Ossur's Ottobock X3, are cost prohibitive for most households, ranging in price from $18000 to $100000.

The MRF Knee conoid's innovative and unique design was created as a proof of concept to demonstrate how increasing the contact surface area between the MRF and the magnetized solid could potentially increase resistive torque. The MRF Knee had to be able to complete various criteria which included:

- Provide 20.65 ft lb. (28Nm) Resistive Torque
- Max Load of 180 lb. (800N)
- Max Apparatus Weight: 5 lbs.
- Easy to assembly and disassembly
- Cost efficient and affordable (> $2000/knee)

Background

- Magnetorheological Fluid (MRF) is created by having magnetic particles suspended in a type of oil.
- When a magnetic field is applied to the fluid, it becomes more viscous and clings to the walls of its container.
- This property allows it to be used to create a braking force in the device created in this project.

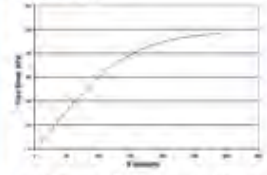

Figure 1: Stress vs. Field Intensity in MRF [1]

Figure 2: Main MR-brake designs: (a) drum, (b) inverted drum, (c) T-shaped rotor, (d) disk, (e) multiple disks [2]

- Figure 2 above shows the main types of brakes that use MRF that are currently being used.
- Drum types have a small radius and large width, and the braking force is applied to the rounded outer wall of the rotor.
- Disk types have a large radius and small width, with the braking force applied to the flat radial walls of the rotor.
- T-types are shaped as the name suggests, and has the braking force being applied to several walls at the same time.

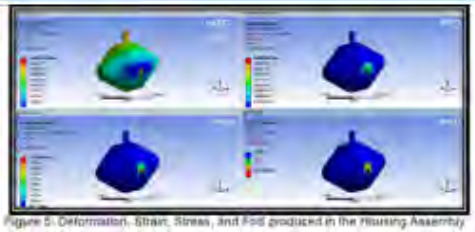

Figure 5: Deformation, Strain, Stress, and FoS produced in the Housing Assembly

Figure 6: Position of Knee Brake with Battery Pack

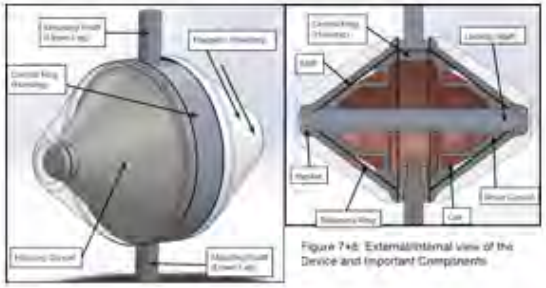

Figure 7+8: External/Internal view of the Device and Important Components

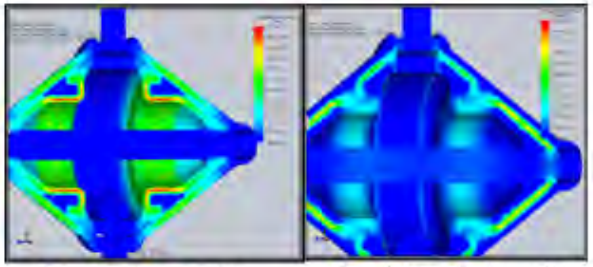

Figure 9: Magnetic Flux Density Plot

Figure 10: Magnetic Field Intensity Plot

Results

Stress(von Mises)	
Maximum (PSI):	2.504×10^3
Occurs On:	Housing Central Ring
Component Composition:	Aluminum T6
Knee Position:	Bent 90 deg

Table 1: Maximum von Mises Stress

Equivalent Elastic Strain	
Maximum (in)/(in):	2.9
Occurs On:	Housing Central Ring
Component Composition:	Aluminum T6
Knee Position:	Bent 90 deg

Table 2: Maximum Elastic Strain

Total Deformation:	
Maximum (in) (m):	0.01in (2.54E-4)
Occurs On:	Housing Magnetic Insulator
Component Composition:	ABS Plastic
Knee Position:	Straight

Table 3: Maximum Deformation

Factor of Safety	
Min (in)/(m):	1.5913
Occurs On:	Housing Central Central Ring
Component Composition:	Aluminum T6
Knee Position:	Bent 90 deg

Table 4: Minimum Factor of Safety

Figure 3: Femm 4.2 magnetic field intensity plot

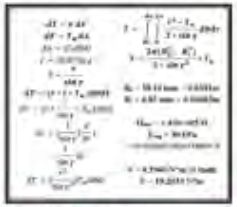

Figure 4: Torque Calculations

- The plot shown in Figure 3 was created using FEMM 4.2 to model the magnetic field intensity acting through the fluid, with 0 length being where the conoids meet the central rings.
- The average magnetic field intensity acting through the fluid is about 100 kAmp/m.
- The average is then used in Figure 1 to find the average stress created to be about 30 kPa.
- This is then used in Figure 4 to determine the torque acting against the motion of the knee.
- Tables 1-4 show the largest stress, strain, deformation, and lowest factor of safety in the device and where it occurs.

Conclusion

At this point in the project, testing is currently underway, so the results presented are based on theoretical calculations. These results indicate that the device will only support a 150lb. person, even though the project statement intended for supporting 250lbs. This is not considered a failure in engineering terms, it is the first attempt at creating a device that will only improve with future modifications.

Sponsors

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References

[1] MRF-132DG Magneto-Rheological Fluid. Retrieved from LORD Corporation: lord.com
[2] Avraam, M. H., Horvatic, I. B., Kostovska, M. A., Petrovski, T. Computer Control of Multipoint MR-Based Vibration Isolation System. Journal of Intelligent Material Systems and Structures 21, 13 (2010): 1343-1357.

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