ANALYTICAL ANALYSIS: PIN TOLERANCE AND LIMITS

Active Prosthesis

NORTHERN ARIZONA UNIVERSITY

College of Engineering, Forestry & Natural Sciences

Antoinette Goss
Team 12 Active Prosthetic
ME 476C-5 Mechanical Engineering Design
March 1, 2019

1 Introduction

One of the most important components of any engineering project is determining the tolerances from manufacturing. The size of the tolerance affects the cost of the manufacturing process as the smaller the tolerance, the larger the cost. The team wishes to make the pins with the largest tolerance possible for ease of fabrication and to ensure that the part will not break. The purpose of this analytical analysis is to determine the tolerance and limits of the different connectors that will be used for the arm. Using a mathematical approach, the sized holes will then be 3D printed to confirm whether the holes are appropriate for future use. If the initial experiment is incorrect, a new tolerance will be made based on the different printed holes.

2 Concepts and method

2.1: Background

Determining the tolerances of connectors minimizes the variation during manufacturing. This dimension is key in ensuring a tight fit that will correctly perform its intended function. There are a few fits to choose from depending on the what fit a designer wishes for. For the active prosthetic device, the connections will be clearance locations fit. Meaning, the connections pins will be a smaller diameter than the holes in the arm. This fit allows for easy assembly and disassembly which is ideal for a product designed for consumers to be able to assemble themselves. Based on this fit, the correct tolerance and deviation equations can be selected.

2.2 Equations

The first necessary dimension is determining the basic size of the shaft. The 3D printer will have issues if the pin is any smaller than a diameter of 1/8 of an inch. Any smaller size will likely break the pin. It was determined that the finger size would be at a diameter of .167 inch for the shaft. The cuff would need to be at a slightly larger diameter while still allowing the cuff to rotate. Based on the dimension of the Enable arm, the shaft of the cuff pin was set at .2035 in. The forearm pins will be the same diameter of the cuff, but with a slightly longer shaft for a hinge-like connection. Once the basic numerical values were set, the tolerance and deviance equations could be derived.

The tolerance and deviation values can be collected from the table in Shigley's design textbook. The corresponding class for a location clearance fit is H7g6. According to the table, this fit would have a tolerance of .003 for the finger diameter and .004 for the cuff and forearm connections. The deviation value appears to be zero for both. Using the tolerance, the max diameter, minimum diameter, and deviance can be calculated using the following equations.

$$D_{max} = D + \Delta D \quad (1)$$

$$D_{min} = D \quad (2)$$

Where D is the basic size diameter and ΔD is the Tolerance of the hole. D_min is simply equal to the basic size. These equations can then be used to find the deviation. Below are the equations.

$$d_{max} = D + \delta_f \quad (3)$$

$$d_{min} = D + \delta_F - \Delta D \quad (4)$$

Finally, the values can be used to understand the interference. Following the book, the equations are stated below.

$$\delta_{min} = d_{min} - D\_max \quad (5)$$

$$\delta_{max} = d\_\max - D\_min \quad (6)$$

It is important to have thee equations to compute, even if they may not be accurate for a PLA design. All forces and pressure equations were not evaluated for this analysis. The tolerance and size were the only necessary considerations needed.

Method of experimentation

These equations were placed into an excel file that could easily calculate the max and min diameter as well as the interference. This excel can be found below. The excel is adjusted for both inches and millimeters. These tolerances and equations are only based on the given tolerances in the book. PLA is a fairly new material and therefore, it is suspected that the tolerances or possibly even the hole initially will not work. As a result, this experiment is based in two parts, one on the initial calculations, and the other on the adjusted tolerance based on experimental testing.

Units		inch		Symbol	H7/h6	
Basic size	D, d	0.2035	in		5.1689	mm
Tolerance Range					0–3	
Deviation Range					0–3	
Hole tolerance	DD	7			3	
		0.0004	in		0.010	mm
Shaft deviation	dF	h			6	
		0.0000	in		0.000	mm
Shaft tolerance	Dd	6			2	
		0.0002	in		0.006	mm
Hub modulus	Eo	507	ksi		510	MPa
Hub Poisson	no					
Shaft modulus	Ei	74	ksi		510	MPa
Shaft Poisson	ni	507				
Hub OD	do	0.31	in			
Shaft ID	di	0.25	in			
Friction Factor	f					
Hub Length	l	0.1	in			
Diametral interfence, MMC	dmax	0.000	in	Eq. 7-43		
Diametral interfence, LMC	dmin	-0.0004	in	Eq. 7-42		
Eq 7-39 A		2.51450				
Eq 7-39 B		########				

	Dimensions			
Hole MMC	Dmin	0.2035	in	Eq. 7-36
Hole LMC	Dmax	0.2039	in	Eq. 7-36
Shaft MMC	dmax	0.2035	in	Eq. 7-37
Shaft LMC	dmin	0.2035	in	Eq. 7-37
Max Clearance		0.060		

Units		
mm\in	25.4	
mm		
inch		
MPa\ksi	6.8947	
E_PLA	510	ksi

Figure1: Excel Calculations

3 Solidworks Design

The experiment portion is to simply confirm if the sizes and corresponding tolerances are ideal for assembly. In order to do so, a 3D printed hole and pin were made to physically test the sizes. There were two size holes that were made, one within the tolerance of the basic size and one at a slightly looser fit. Below are picture results of the 3D printed pins and holes.

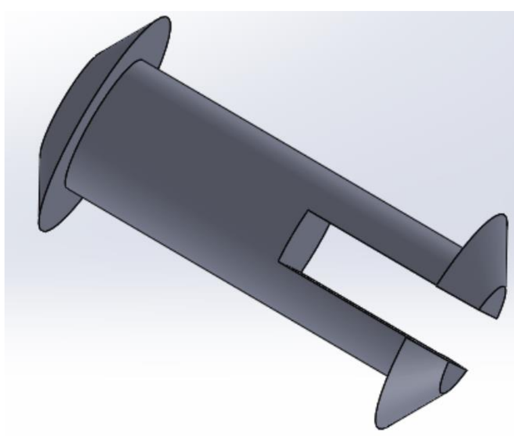

Figure2: Basic Design of Pin

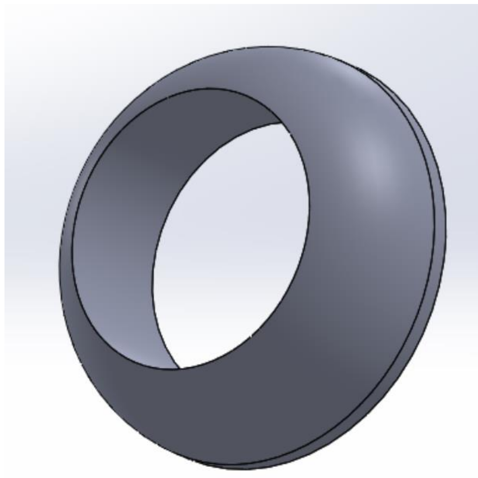

Figure3: Basic Design of Hole

The hole design will be adjusted for the same size pin. The shaft will remain the same through the entirety of the experiment. The two different holes were kept at the initial sizing and about .005in out of the tolerance calculated to see if the tolerance is accurate for Pla material.

4 Results

As feared, the tolerances of PLA operate in a completely different fashion than that of steel or other plastic materials. Thermal expansion, plastic warping, and 3D printing methods all affect the hole size. The smaller pin was able to get in to the larger hole out of the tolerance initially but the larger could not get through due to the warping and expansion of the material. Even though the smaller pin got through, it still required a significant force to do so, disqualifying the fit as a clearance fit and more so of an interference fit. Below shows a result of the broken smaller pin from forcing it through the hole.

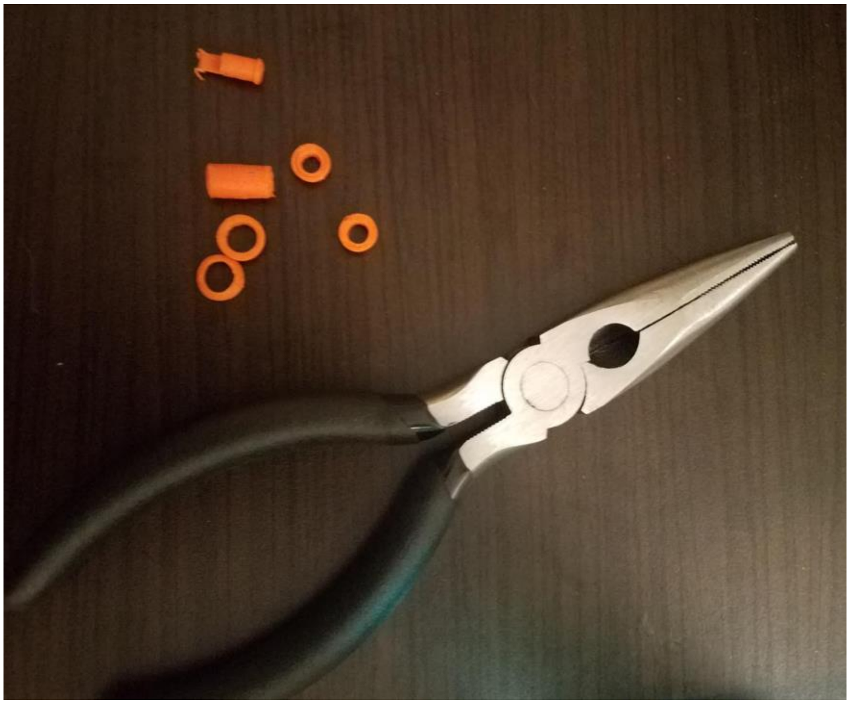

Figure 4: Experiment Layout

Figure 5: Figure of the smaller pin with successful sized hole

Form this failed result, a new approach will be taken. According to a designer Scott Cahoon, he has experienced the same difficulties in tolerances and found that only testing different sizes could he find a tolerance needed.

5 Experiment 2: The Test Approach

Because of this failed experiment, a new approach must be taken. Five different holes for each pin were made starting at 005in larger than the largest calculated tolerance. This was done to ensure that the tolerances were made and correctly adjust for the larger shaft size. The different hole sizes were made with a .005in difference between each iteration. This would be an experimental way of determining exactly how big the tolerance must be for the holes to be a clearance locational fit as desired. Each hole can be tested again the pin until the hole size remains too big. Figures form the experiment can be found below.

Figure 6 : Holes for New Experiment

Figure 7: Larger Pin Fit

Figure 8: Smaller Pin Fit

Based on this experiment, the measured tolerance for the small hole is about .005 And .01 for the bigger hole. While not definite, this tolerance falls under the limits for a locational clearance fit. There is still uncertainty as the holes only had a .005 variance between each size, but the approximation still yields a good fit. The best size for the smaller pin was found to be at around .182 inches and about .2335 inches. This tolerance still allows them to be at the locational clearance fit.

Conclusion

Often as engineers, designing, manufacturing, and assembling all require some type of leniency or creative approaches to certain hurdles. Tolerances are typically a set perfected measurement to ensure a part can be assembled correctly. The purpose of this analysis was to ultimately determine the correct fit and tolerance for a clearance location fit on a PLA hole and pin system. It was determined through experimentation, not computational methods, the best course of action when considering how to properly attach all components of the arm. The results of this experiment can be used for a successful active prosthetic arm design going forward.

5 References

[1] H. Gibson, "Calculating Locational Tolerances," Apr. 2013.

[2] R. G. Budynas and J. K. Nisbett, *SHIGLEYS MECHANICAL ENGG DESIGN*, 10th ed. Penn, NY: MCGRAW-HILL EDUCATION (AS, 2014.

[3] S. Cahoon, "MatterHackers Lab: Design 3D Printed Assemblies," *MatterHackers*. [Online]. Available:https://www.matterhackers.com/articles/matterhackers-lab:-design-assemblies-. [Accessed: 31-Feb-2019].