

Design for manufacturing (DFM) criteria-Incorporation of pattern allowances for casting of a Bush model

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Abstract

Patternmaking plays a crucial role in sand-casting process. This paper discusses the DFM criteria of pattern allowances for a Bush model casting. Here an algorithm is developed for incorporating all the allowances just by giving input the part model to be casted and the final output from the algorithm is the modified pattern dimension. The calculation of dimensions for the pattern after various allowances like shrinkage, machining and draft are done in a sequential manner. The initial design is done in the modelling software SolidWorks 2016 and then the allowances are incorporated one by one. Finally, the modified dimension for the pattern is calculated. In this paper, an overall process by which the final dimension of a pattern can be calculated by following a particular sequence of pattern allowances are discussed. The calculation sequence developed may be helpful for various students and casting technicians to find the accurate pattern dimensions.

Keywords: Bush model, Pattern, Allowance, SolidWorks

1. Introduction

The design for manufacturing (DFM) criteria is an important tool to reduce the unnecessary manufacturing cost and to make the manufacturing process easy and error-free. It focusses on individual part fabrication. It is important to have the revision or change in the product in the design stage only to avoid expensive change at the subsequent stages like tooling or production stages. The DFM criteria helps in achieving a product which is simple to produce and cost effective. It also guides to increase the product functionality, reliability and durability [12][13].

In the manufacturing process of casting, the metal parts are produced by pouring liquid molten metal into a mould cavity where the cooling or solidification of the part is formed in the desired shape and size [1]. For creating this mould cavity, we need some pattern. The pattern is the replica of the casted part to be produced by the casting method [2]. So, in this pattern design we need to consider some allowances as the final casted part may not be of same dimension due to various reasons like shrinkage during solidification of the metal, machining the surfaces of the part, easy removal of the part from the mould cavity and to avoid distortions generated in the part in various complex shaped parts [3]. So, the allowances provided in the pattern are shrinkage or contraction allowance, machining or finishing allowance, draft or taper allowance and miscellaneous allowances like shaking or tapping allowance and distortion allowance [4]. By incorporating these allowances, the final part derived will have the desired dimensions. Thus, the pattern dimension is not same as the final casted product.

One of the significant issues in pattern design is the order of allowances to be provided which yields the most exact final part dimensions. So, in the design stage only, the dimension of the pattern needs to be finalised using DFM criteria. Because after the prototyping stage of the product design, the changes may be costly and thus may increase the overall manufacturing cost of the product [14]. So, the calculation of the pattern dimensions is iterated for all the allowances in a sequential manner in order to get a framework for pattern dimensions.

In case of shrinkage, there are three types of shrinkage during solidification. First type is the liquid shrinkage where the metal contraction takes place during cooling of the metal in liquid phase. Second type is the solidification shrinkage where the contraction of the metal takes place during the phase change of the metal from liquid to solid. And the third type is the solid shrinkage where the metal contraction takes place in the solid phase only [5]. The compensation of the liquid and solidification shrinkages are provided with the help of a riser to the mould cavity which feeds liquid molten metal. Shrinkage allowance only provides for the solid shrinkage [6][7]. The casted part produced does not have a smooth surface finish. So, a finishing or machine allowance is provided for the surfaces of the part by increasing the size of the pattern [8][9]. Moreover, if the walls of the pattern are vertical, then removing from the mould cavity is challenging. So, to avoid damage to the cavity walls, the vertical walls of the pattern are made tapered. This allowance provided is called as taper or draft allowance. The draft

angle will depend upon the type of material and varies inversely with height of the wall. The next allowance is the shake or rapping allowance which provided when the pattern is to be removed from the cavity a small tap or shake is given so that it easily comes out of the cavity and thus the pattern should be made dimensionally smaller as the shake makes the cavity larger. So, the tapping allowance is a negative allowance. Another allowance given is the distortion or camber allowance in the metal parts which change or deform their shapes due to internal stress.

In this paper designing of pattern dimensions for Bush casting is discussed. The detailed process of calculating the dimension of the pattern after each allowance is provided and finally the modified pattern is made. Here the tapping and distortion allowance are neglected as these changes are negligible based on the size and shape of the casting part.

1.1 Specifications of the Bush model

The part selected for our study is a small sized Bush model which is made of bronze material. The Bush model is selected for its simple geometry and ease of manufacturability using sand-casting methods [10]. The detailed drafting of the Bush model dimensions is done in SolidWorks 2016 software and it is shown in *figure 1.1*.

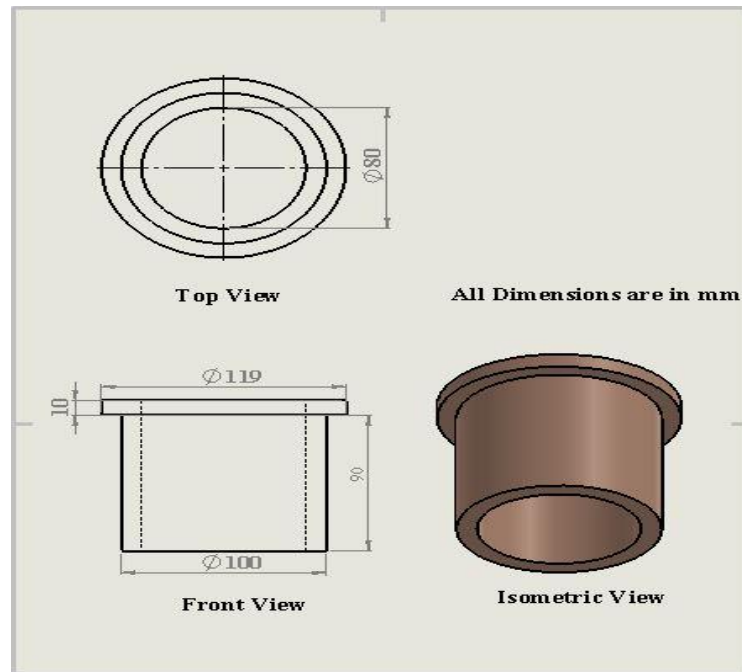


Figure 1.1: Detailed drafting of the Bush model in SolidWorks 2016

As observed from the *figure 1.1*, the outer diameter of the bush is represented as D , inner diameter as d , collar diameter as D_1 , collar length as L_1 and the Bush length as L_2 . For a typical small sized Bush, the dimensions can be taken as outer diameter (D) 100 mm, inner diameter (d) 80 mm, collar diameter (D_1) 119 mm, collar length (L_1) 10 mm and the Bush length (L_2) 90 mm.

2 Methodology

For designing the pattern, as mentioned in the section 1.1, there are some allowances which are needed to be calculated and incorporated into the final pattern dimensions. A step-by-step provision of allowances is given starting from the shrinkage allowance as discussed in the following sub sections.

2.1 Development of an optimum algorithm for the pattern design

An algorithm is developed where the input to the program is given as model of the part to be casted and the material. The algorithm updates the dimension of the pattern by incorporating all the allowances and then as output it gives the final modified dimension of the pattern. The detailed flow chart for the algorithm is given in *figure 2.1* below.

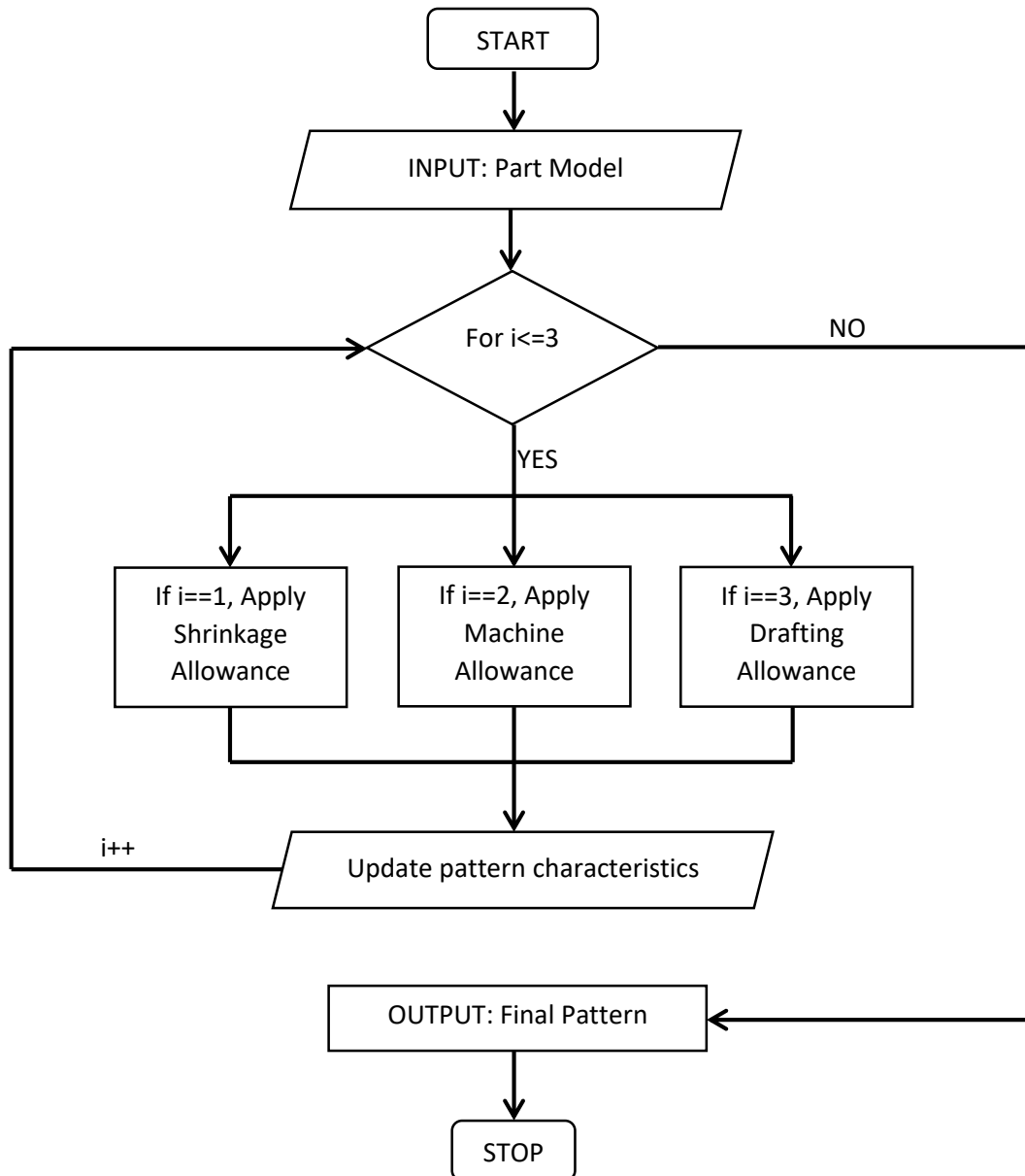


Figure 2.1: Flow chart for the optimum algorithm for pattern design

The model also contains the material information of the part. In the algorithm, a loop is started which terminates with three iterations thereby applying the three allowances. The algorithm ends with giving the modified pattern characteristics (dimensions) as the output.

2.2 Incorporation of shrinkage allowance in pattern dimensions

The first step is to provide the shrinkage or contraction allowance because when the molten metal is poured into the cavity then it contracts or shrinks during the solidification process thereby decreasing the volume. The decrease in the volume of the Bush during the solidification process is compensated by increasing the pattern's external dimensions and decreasing the internal dimensions like hole, bore. This is done because the shrinkage effect may help in removal of the part from the external edges but may lock the part in case of internal dimensions like internal hole or bore. For a typical small sized bronze casting, the shrinkage or contraction allowance is about 10.5 to 21 mm per metre. For this Bush casting, the shrinkage allowance is taken as 16 mm per metre. Now the updated dimensions for the Bush pattern after shrinkage allowance is provided, are calculated as- Bush outer

diameter $D(1)$ is 103.2 mm, inner diameter $d(1)$ is 77.44 mm, collar diameter $D_1(1)$ is 122.808 mm, collar length $L_1(1)$ is 10.16 mm and bush length $L_2(1)$ is 91.44 mm. The detailed calculation is shown in the annexure attached.

2.3 Incorporation of machining allowance in pattern dimensions

The updated dimensions after shrinkage allowance are calculated in section 2.2, now the next step is to provide the machining or finishing allowances to improve the surface finish of the casting part. Thus, in this allowance some increase in external dimensions and decrease in internal dimensions are provided which are to be removed by machining process while smoothening the surfaces of the Bush. For a non-ferrous metals like bronze, the machining allowance for cope side surface it is 3 mm, for other surfaces it is 1.5 mm and for inner bore surface it is 1.5 mm. Now the updated dimensions for the Bush pattern after machining allowance is provided, are calculated as- Bush outer diameter $D(2)$ is 106.2 mm, inner diameter $d(2)$ is 74.44 mm, collar diameter $D_1(2)$ is 125.808 mm, collar length $L_1(2)$ is 14.66 mm and bush length $L_2(2)$ is 92.94 mm. The detailed calculation is shown in the annexure attached.

2.4 Incorporation of draft allowance in pattern dimensions

The second iteration of updated dimensions after machining allowance are calculated in section 2.3, now for easy removal or withdrawal of the pattern from mould cavity without damaging the sand cavity, draft or taper allowance is provided. In this allowance the vertical surfaces are made somewhat tapered so that it can be easily removed from the sand cavity. For any metal casting the draft allowance for external surfaces it is 0.35° to 1.5° and for internal surfaces it is 0.5° to 3° . For this casting of the Bush part, the external surface draft allowance is taken as 0.93° while the internal surface draft allowance is taken as 1.75° . After the draft allowance is provided, one end of every cylindrical diameter is changed from the original one. So, some new dimensions are generated whose schematic is shown in *figure 2.2*.

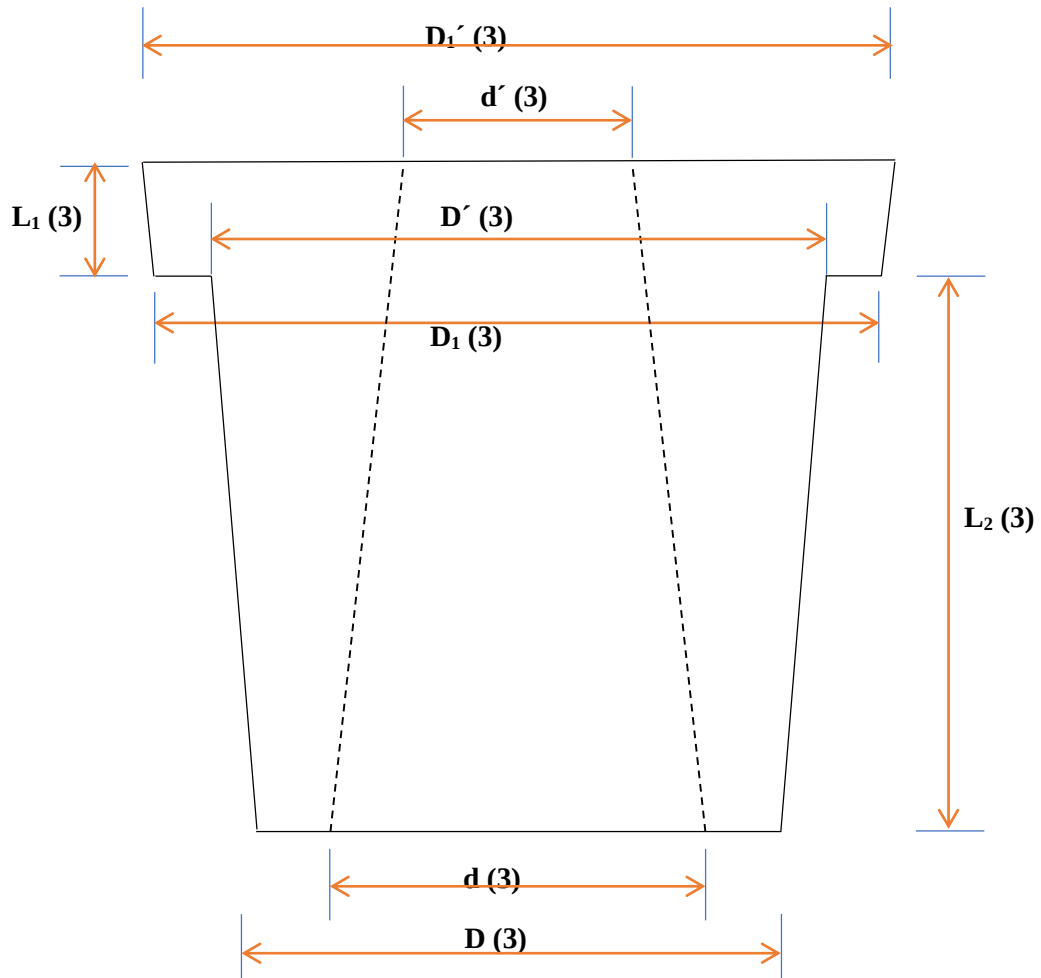


Figure 2.2: Schematic of final Bush pattern after draft allowance

Now the updated dimensions for the Bush pattern after draft allowance is provided, are calculated as-Bush outer diameter $D(3)$ is 106.2 mm, top outer diameter $D'(3)$ is 109.217388 mm, inner diameter $d(3)$ is 74.44 mm, top inner diameter $d'(3)$ is 67.8650453 mm, collar diameter $D_1(3)$ is 125.808 mm, collar top diameter $D_1'(3)$ is 126.283951 mm, collar length $L_1(3)$ is 14.66 mm and bush length $L_2(3)$ is 92.94 mm. The detailed calculation is shown in the annexure attached.

3 Results and Discussion

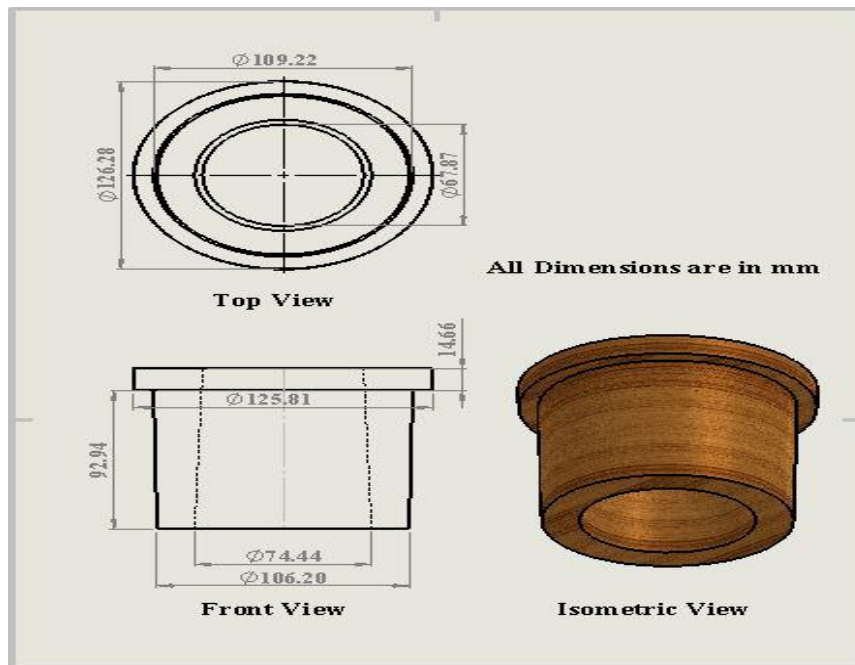


Figure 3.1: Detailed drafting of the final pattern of the Bush model in SolidWorks 2016

The development of the flow chart which suggested the order of applying the pattern allowances has provided a framework for calculation of pattern dimensions for all students, engineering and other foundry professionals. The framework guides the methodology of calculation of the pattern dimensions by applying various allowances one after another depending on the significance. First calculation is regarding the shrinkage allowance and then machining allowance followed by the draft or taper allowance. After each iterations dimensions of the pattern is updated and modified.

The calculations shown in annexure 1.3 are the final iterations of the pattern dimensions after providing all the necessary allowances. Other allowances like shaking or distortion allowances are ignored in this case of Bush model. The material of the pattern is taken as teak wood. A peculiar observation in the final pattern dimensions is that some extra dimensions have emerged which are due to the result of the draft allowance. The final pattern of the Bush model is drafted in SolidWorks 2016 software and it is shown in *figure 3.1*.

5 Conclusion

The paper paints a picture for overall order or sequence of allowances to be provided to the pattern. It may be challenging to decide which allowance to be provided first and which to next. This paper took this issue and provided an optimum sequence as how to provide the allowances one after the other. Thus, the optimum approach for deciding the sequence or order of the allowances is firstly the shrinkage, then machining and then drafting allowances are provided. The calculations reflect the final pattern dimensions. These sequential applications of the allowances are presented in the form of an algorithm which can be coded for better calculations and reduced error. As it is a sand-casting process, the exact replication of the dimension is challenging. Many algorithms can be developed which are advanced and can help in determining accurate pattern dimension in future. So, a proper caution in the patternmaking process may reduce the ambiguity and defects in the casted part. The framework

developed in this paper may utilised for various applications of sand casting as well as can be extended to complex and intricate shaped castings also.

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Annexure

1.1 Calculation for Shrinkage allowance:

$$\text{Bush outer diameter, } D(1) = D + [2 \times (D \times \frac{16}{1000})]$$

$$\Rightarrow D(1) = 100 + [2 \times (100 \times \frac{16}{1000})]$$

$$\Rightarrow D(1) = 103.2 \text{ mm}$$

$$\text{Bush inner diameter, } d(1) = d - [2 \times (d \times \frac{16}{1000})]$$

$$\Rightarrow d(1) = 80 - [2 \times (80 \times \frac{16}{1000})]$$

$$\Rightarrow d(1) = 77.44 \text{ mm}$$

$$\text{Bush collar diameter, } D_1(1) = D_1 + [2 \times (D_1 \times \frac{16}{1000})]$$

$$\Rightarrow D_1(1) = 119 + [2 \times (119 \times \frac{16}{1000})]$$

$$\Rightarrow D_1(1) = 122.808 \text{ mm}$$

$$\text{Bush collar length, } L_1(1) = L_1 + (L_1 \times \frac{16}{1000})$$

$$\Rightarrow L_1(1) = 10 + (10 \times \frac{16}{1000})$$

$$\Rightarrow L_1(1) = 10.16 \text{ mm}$$

$$\text{Bush length, } L_2(1) = L_2 + (L_2 \times \frac{16}{1000})$$

$$\Rightarrow L_2(1) = 90 + (90 \times \frac{16}{1000})$$

$$\Rightarrow L_2(1) = 91.44 \text{ mm}$$

1.2 Calculation of Machining allowance:

$$\text{Bush outer diameter, } D(2) = D(1) + (2 \times 1.5)$$

$$\Rightarrow D(2) = 103.2 + (2 \times 1.5)$$

$$\Rightarrow D(2) = 106.2 \text{ mm}$$

$$\text{Bush inner diameter, } d(2) = d(1) - (2 \times 1.5)$$

$$\Rightarrow d(2) = 77.44 - (2 \times 1.5)$$

$$\Rightarrow d(2) = 74.44 \text{ mm}$$

$$\text{Bush collar diameter, } D_1(2) = D_1(1) + (2 \times 1.5)$$

$$\Rightarrow D_1(2) = 122.808 + (2 \times 1.5)$$

$$\Rightarrow D_1(2) = 125.808 \text{ mm}$$

$$\text{Bush collar length, } L_1(2) = L_1(1) + 1.5 + 3 \text{ (More machining allowance for cope i.e., top surface)}$$

$$\Rightarrow L_1(2) = 10.16 + 1.5 + 3$$

$$\Rightarrow L_1(2) = 14.66 \text{ mm}$$

$$\text{Bush length, } L_2(2) = L_2(1) + 1.5$$

$$\Rightarrow L_2(2) = 91.44 + 1.5$$

$$\Rightarrow L_2(2) = 92.94 \text{ mm}$$

1.3 Calculation of Draft allowance:

$$\text{Bush outer diameter, } D(3) = D(2)$$

$$\Rightarrow D(3) = 106.2 \text{ mm}$$

Bush top outer diameter, $D'(3) = D(2) + [2 \times \tan(0.93^\circ) \times L_2(2)]$

$$\Rightarrow D'(3) = 106.2 + [2 \times \tan(0.93^\circ) \times 92.94]$$

$$\Rightarrow D'(3) = 109.217388 \text{ mm}$$

Bush inner diameter, $d(3) = d(2)$

$$\Rightarrow d(3) = 74.44 \text{ mm}$$

Bush top inner diameter, $d'(3) = d(2) - [2 \times \tan(1.75^\circ) \times (L_1(2) + L_2(2))]$

$$\Rightarrow d'(3) = 74.44 - [2 \times \tan(1.75^\circ) \times (14.66 + 92.94)]$$

$$\Rightarrow d'(3) = 67.8650453 \text{ mm}$$

Bush collar diameter, $D_1(3) = D_1(2)$

$$\Rightarrow D_1(3) = 125.808 \text{ mm}$$

Bush collar top diameter, $D_1'(3) = D_1(2) + [2 \times \tan(0.93^\circ) \times L_1(2)]$

$$\Rightarrow D_1'(3) = 125.808 + [2 \times \tan(0.93^\circ) \times 14.66]$$

$$\Rightarrow D_1'(3) = 126.283951 \text{ mm}$$

Bush collar length, $L_1(3) = L_1(2)$

$$\Rightarrow L_1(3) = 14.66 \text{ mm}$$

Bush overall length, $L_2(3) = L_2(2)$

$$\Rightarrow L_2(3) = 92.94 \text{ mm}$$