

## ***Computer Aided Tolerance Analysis for Press Tool Die Set to Improve the Process Control & Tolerance Allocation***

***Subodh Kumar<sup>1</sup>, Ramkisan Pawar<sup>2</sup>, Gopal Devidas Belurkar<sup>3</sup>***

*Principal<sup>2</sup>, Senior Engineer<sup>3</sup>*

*Shreeyash College of Engineering & Technology, Auranagbad<sup>1,2</sup>*

*Indo German Tool Room Aurangabad<sup>3</sup>*

***Corresponding Authors' Emails:*** *subodhceb@gmail.com<sup>1</sup>, ramkisanpawar1972@gmail.com<sup>2</sup>,  
belurkargopal@gmail.com<sup>3</sup>*

### ***Abstract***

*This paper describes a study for blanking tool, where tolerance analysis and tolerance allocation techniques were used to analyze the cause of poor product performance and determine new tolerance specifications and process settings. 1D stackup analysis were performed by CREO CETOL. In blanking or piercing operation punch and die should concentric for proper cutting. Paper describe the cumulative effect of tolerance during alignment of punch and die.*

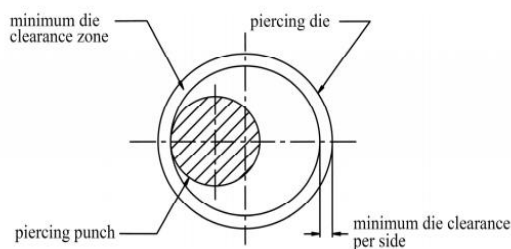
***Keywords:*** *Blanking, GD&T, DMPU, Press Tool, Stackup Analysis, Tolerance Allocation, Yield Percentage*

### **I. INTRODUCTION**

In sheet cutting operation, the quality of the product and the tool life is mainly depends upon the punch and die clearance. For proper cutting operation cutting clearance between die and punch should be even around the die. Cumulative effect of tolerance affect the clearance of die and punch, results into poor Cutting operation

and poor edge quality of the blanked component. Cutting clearance depend upon thickness & material of Sheet metal. Cumulative effects tolerance result into uneven distribution of cutting clearance. Since many experiment have been done and it has been validated that proper clearance around the die and punch is required for proper and burr free component

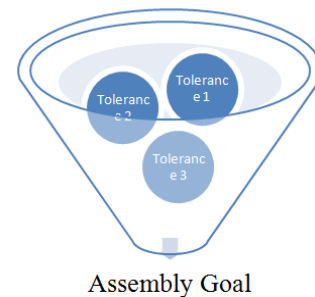
[1][2][3][4][5][6][7][29][30]. Kaliaperumal Ragu [1], experimentally it had found that unevenness can be controlled by defining a zone called 'minimum die clearance zone' as shown in see figure 1 [1]. Author Suggest that considering the criticality of the product, the minimum die clearance zone per side is chosen as 5% of the feedstrip thickness. To achieve the minimum clearance zone designer should assign the tolerance to the press tool part which contribute minimum to the tolerance accumulation during assembly.



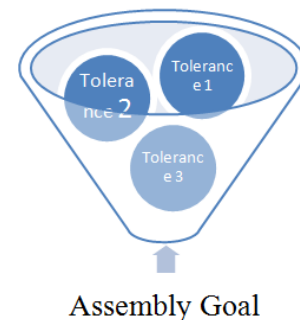
**Figure 1 Minimum clearance zone [1]**

Generally designer assign the tolerance to the parts according to their past experience or best fit method. There are number of traditional method which use to assign the tolerance to the parts of an assembly considering their functionality. Conventional tolerancing is useful to decide the fitment of the assemble parts. GD&T is useful to achieve the functionality & design intent of

thecomponent during it function. Position tolerance usually gives 57 percentage of product acceptability than conventional tolerancing approach [32] [36]. Stackup analysis, or tolerance analysis is the method is used to calculate the cumulative effect of tolerance in an assembly. First tolerance are assigned and then their effect analyze as a goal of an assembly. Tolerance allocation method is use to assign the tolerance to the component of an assembly for predetermined goal of an assembly [10] [16] [32]. (See Figure 2)



**Figure 2 a) Tolerance analysis**



**b) Tolerance allocation**

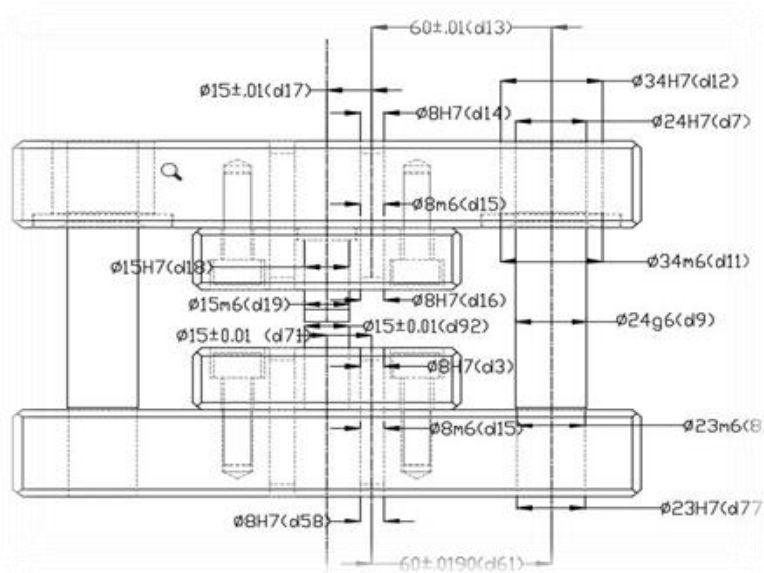
Worst case & Statistical methods are traditional method which is use for tolerance analysis. Worst case assume that dimension

will produce at its extreme. Statistical tolerance analysis assume dimension distributions are centered on the midpoint of the dimension. Worst case is useful for an assembly having minimum number of component and Statistical tolerance analysis is for large number of components. [16] [32]

These tolerance analysis method are incorporated in computer added tolerancing package CETOL for 1-D & 3D analysis. Many other cad package is also available by different cad Software Company. CAD Tolerancing package is very useful to calculate the cumulative effect of tolerance and accordingly assign the tolerance on the basis of percentage contribution of

tolerances. Tolerance analysis and tolerance allocation can be done simultaneously in CAD tolerancing package.

This paper describe a study of a simple blanking tool. Tolerance analysis and tolerance allocation method was used to determine the improved tolerance specifications for press tool parts to control the uneven distribution of cutting clearance for die and punch. The data for Press tool design taken from the hand book of die design.



**Figure 3. Assembly of press tool with loop dimension for tolerance analysis**

Cutting clearance is one of the design parameter of press tool. Cutting clearance affects the manufactured component. Large cutting clearance results into burr and less cutting clearance result into crack generation at cutting edge. Simultaneously increase the friction in-between die, punch and sheet that results decreases the life of tool. An assembly of press tool to perform blanking operation to produce a circular blank of 15mm. (See Figure 2).

## II. CALCULATION

### A. Cutting clearance calculation for 1 mm sheet thickness for feedstrip

Cutting clearance ( $CL_{side}$ ) for 1 mm sheet [30]

$$CL_{side} = ct \quad \text{Eq. 1}$$

Where  $t$  = material thickness = 1mm

$S$  = shear strength of material = 345 Nmm<sup>-2</sup>

$c$  = constant, for materials generally it is taken .0035

$$\begin{aligned} \text{Thus cutting clearance} &= .0035 * 1\text{mm} * \sqrt{3} \\ &= .065 \text{ mm per side} \end{aligned}$$

### B. Calculating the Mean Value (Gap) for the Requirement

The first step in calculating the variation at the gap is to calculate the mean value of the requirement. The mean value at the gap is:

$$d_g = \sum_{i=1}^n a_i d_i \quad \text{Eq. 2}$$

Where

$d_g$  = the mean value at the gap. If  $d_g$  is positive, the mean “gap” has clearance, and if  $d_g$  is negative, the mean “gap” has interference.

$n$  = the number of independent variables (dimensions) in the stackup

$a_i$  = sensitivity factor that defines the direction and magnitude for the  $i_{th}$  dimension. In a one dimensional stackup, this value is usually +1 or -1. Sometimes, in a one-dimensional stackup, this value may be +.5 or -.5 if a radius is the contributing factor for a diameter callout on a drawing.

$d_g$  = the mean value of the  $i_{th}$  dimension in the loop diagram.

Nominal shift in between die & punch requirement 1 =

$$(+1) d_{71} + (+1) d_{61} + (-1) d_{13} + (-1) d_{17}$$

Nominal shift in between die & punch requirement 1 = 15+60-60-15 =0.00 mm

Nominal shift in between die & punch requirement 1 = 0.00 mm

### **C. Worst Case Model**

The Worst Case Model, sometimes referred to as the “Method of Extremes,” is the simplest and most conservative of the traditional approaches. In this approach, the tolerance at the interface is simply the sum of the individual tolerances. The worst-case analysis will only provide information about dimensions that exceed their respective specified tolerance limits. Mathematically, the model assumes that all the tolerance dimensions will equal to one of their limit values, which yields an extreme stack-up condition.

The following equation calculates the expected variation at the gap.

$$t_{wc} = \sum_{i=1}^n |a_i t_i| \quad \text{Eq. 3}$$

Where

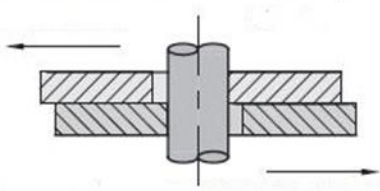
$t_{wc}$ = maximum expected variation using the Worst Case Model.

$t_i$ = equal bilateral tolerance of the  $i^{\text{th}}$  dimension in the stackup.

### **D. Assembly Shift**

Assembly shift represents the amount that parts can move during assembly due to the clearance between a hole and a fastener, a hole and a shaft, a width and a slot (like a key and keyway) or between any external feature within an internal feature. To put it another way, assembly shift accounts for the freedom parts have to move from their nominal locations due to the clearance between mating internal and external features at assembly. It can see that plates are shifting about dowel see figure 4.

Assembly shift is added to the tolerance stackup as a line item without a sign or direction, as it allows the parts to shift in both the positive and negative directions, similar to an equal-bilateral tolerance. Different than a tolerance, assembly shift is a function of mating parts at assembly, and is not associated with a dimension value, nor is it shown with a dimension origin symbol [13] [34] [35].



**Figure 4 shift of plates about a floating dowel**

Assembly shift due to Dowel pin upper half and lower half of assembly of prestool can be calculated as following.

$$\begin{aligned} \text{Worst case assembly shift} &= (\text{LMC of hole} - \text{LMC of the shaft}) \\ &= (\text{dowel hole in die plate at LMC} - \text{dowel pin at LMC}) \\ &= (\max d_3 - \min d_{15}) \\ &= 8.015 - 8.006 = .009 \end{aligned}$$

To convert it into plus/minus bi-equal tolerance =  $.009/2 = \pm .0045$

Due to dowel shift will occur in two plate as shown in Figure 4.

So dowel will lead to total assembly shift into plus/minus bi-equal tolerance ( $S_1$ ) =  $.0045 * 2 = \pm .009$

Similarly we can calculate assembly shift into plus/minus bi-equal tolerance ( $S_2$ ) for upper half that is equal to  $\pm .009$ .

Assembly shift due to guide pillar and bottom plate can be calculated as following.

$$\begin{aligned} \text{Worst case assembly shift} &= (\text{LMC of bottom plate hole} - \text{LMC of guide pillar}) \\ &= (\max d_{77} - \min d_8) = .013 \end{aligned}$$

Convert assembly shift into plus/minus bi-equal tolerance ( $S_3$ ) =  $.013/2 = \pm .0065$

Assembly shift due to guide pillar and guide bush can be calculated as following.

$$\begin{aligned} \text{Worst case assembly shift} &= (\text{LMC of Internal dia. of guide bush} - \text{LMC of guide pillar}) \\ &= (\max d_7 - \min d_9) = .041 \end{aligned}$$

Convert assembly shift into plus/minus bi-equal tolerance ( $S_4$ ) =  $.041/2 = \pm .0205$

Assembly shift due to outer diameter of guide bush and top plate can be calculated as following.

$$\begin{aligned} \text{Worst case assembly shift} &= (\text{LMC of top plate hole} - \text{LMC of guide pillar}) \\ &= (\max d_{77} - \min d_8) = (34.025 - 34.009) = .016 \end{aligned}$$

Convert assembly shift into plus/minus bi-equal tolerance ( $S_5$ ) =  $.016/2 = \pm .008$

Assembly shift due to top plate counter bore hole for holding the punch and punch can be calculated as following.

Worst case assembly shift = (LMC of top plate counter bore hole – LMC of punch)  
= (max  $d_{18}$  – min  $d_{19}$ ) = (15.018 – 15.007) = .014

Convert assembly shift into plus/minus bi-equal tolerance ( $S_6$ ) = .014/2 =  $\pm 0.0055$

Now from the equation 3

Here no need to assign the sensitivity to tolerance value for calculation since tolerance will never subtracted.

$$t_{wc} = t_{71} + s_1 + s_2 + s_3 + s_4 + s_5 + s_6 + t_{61} + t_{13} + t_{17} = .01 + .009 + .009 + .0065 + .0205 + .008 + .0055 + .01 + .01 + .01 = .0985 \text{ mm}$$

Since nominal gap is zero. So maximum and minimum shift that is possible in between die and punch is nominal shift plus worst case tolerance calculation i.e. maximum offset in-between punch and die is .0985 mm per side

Maximum shift in between punch and die = nominal shift + worst case calculation

$$\text{Maximum shift in between punch and die} = d_g + t_{wc}$$

$$= 0 + .0985 = .0985 \text{ mm per side}$$

Since distribution of punch and die should be uniform around the punch. Thus possible offset in between punch and die due to Tolerance of prestool parts may cause the uneven distribution for clearance.

### ***E. Statistical Model (RSS Model)***

$$\text{RSS Tolerance } (t_{rss}) = \text{square root of sum of } (t_i^2) \quad \text{Eq. 4}$$

Where:

$t_i$  = Tolerances in the Tolerance Stackup

So, Eq. (4) assumed that all of the component tolerances represent a  $3\sigma$  value for their manufacturing processes. Thus, if all the component distributions are assumed to be normal, then the probability that a dimension is between  $\pm t_i$  is 99.73%. If this is true, then the assembly gap distribution is normal and the probability that it is  $\pm t_{rss}$  between is 99.73%. Although most people have assumed a value of  $\pm 3\sigma$  for piecepart tolerances, the RSS equation works for

“equal  $\sigma$ ” values. If the designer assumed that the input tolerances were  $\pm 4\sigma$  values for the piecepart manufacturing processes, then the probability that the assembly is between  $\pm t_{rss}$  is 99.9937 ( $4\sigma$ ). [31]

The  $3\sigma$  process limits using the RSS Model are similar to the Worst Case Model. The minimum gap is equal to the mean value minus the RSS variation at the gap. The maximum gap is equal to the mean value plus the RSS variation at the gap. [31]

Nominal shift in between die & punch requirement  $1(dg) = (+1)d_{71} + (-1)d_{61} + (+1)d_{77} + (-1)d_8 + (-1)d_9 + (+1)d_7 + (-1)d_{11} + (+1)d_{12} + (-1)d_{13} + (-1)d_{17} + (+1)d_{18} + (-1)d_{19}$   
 $= (15.00000 + 60.00000 + 11.50525 - 11.50725 - 11.99325 + 12.00525 - 17.00850 + 17.00625 - 60.00000 - 15.00000 + 7.50450 - 7.50625)$   
 $= 0.00600 \text{ mm}$

RSS Tolerance ( $t_{rss}$ ) = Root sum square of individual tolerances ( $t_i$ )

Here  $t_i$  is the bi-lateral tolerance associated with the dimension participating in loop vector.  $s_1$  &  $s_2$  are the assembly shift due to floating dowel pin. (See figure 3)  
 $= \text{Root sum square } (t_{71} + s_1 + t_{61} + t_{77} + t_8 + t_9 + t_7 + t_{11} + t_{12} + t_{13} + s_2 + t_{17} + t_{18} + t_{19})$

$= \text{Root sum square of } (0.01000 + 0.00900 + 0.01000 + 0.01050 + 0.00650 + 0.00650 + 0.01050 + 0.00800 + 0.01250 + 0.01000 + 0.00900 + 0.01000 + 0.00450 + 0.00275)$   
 $= \pm 0.03339 \text{ mm}$

Maximum shift in between punch and die =  $d_g + t_i$   
 $= (0.00600 + 0.03339) = 0.0394 \text{ mm}$

Since it also affect the clearance distribution around the die and punch. Thus it affects the cutting operation and consequences may be as burr and tearing of component during stamping.

#### **F. Minimum Die Clearance Zone Calculation**

Minimum die clearance = 5 percent of Sheet thickness  
 $= .05 \times 1 \text{ mm} = 0.05 \text{ mm per side}$

Thus, Measurement of target value in variation = (Die clearance – Minimum die clearance value)

$= 0.065 - 0.05 = 0.015 \text{ mm. per side}$

### **III. EXPERIMENTAL PROCEDURE**

To maintain the effective even clearance, influence of different tolerance was simulated the blanking of 15- mm-diameter

holes on 1 mm stainless steel sheet with shear strength of material was 345 N/mm<sup>2</sup>.

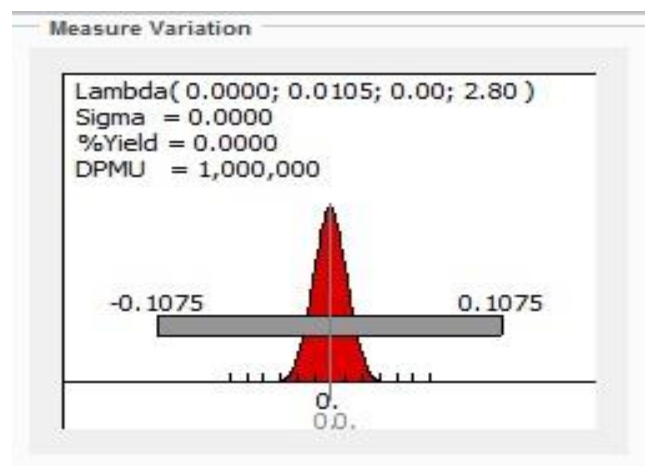
The stack up simulations were carried out using CREO CETOL software and a computer with i5 processor and memory RAM of 4GB.

Solid model of press tool assembly created in creo parametric modeling software. All parts were assigned with tolerance according to their Function and manufacturing process from die design hand book(See figure 2). Assembly model were simulated Stackup analysis considering the maximum variation of 0.015 mm per side. To achieve this goal tolerance of different parts of press tool varied iteratively with the help of computer aided tolerance analysis software package.

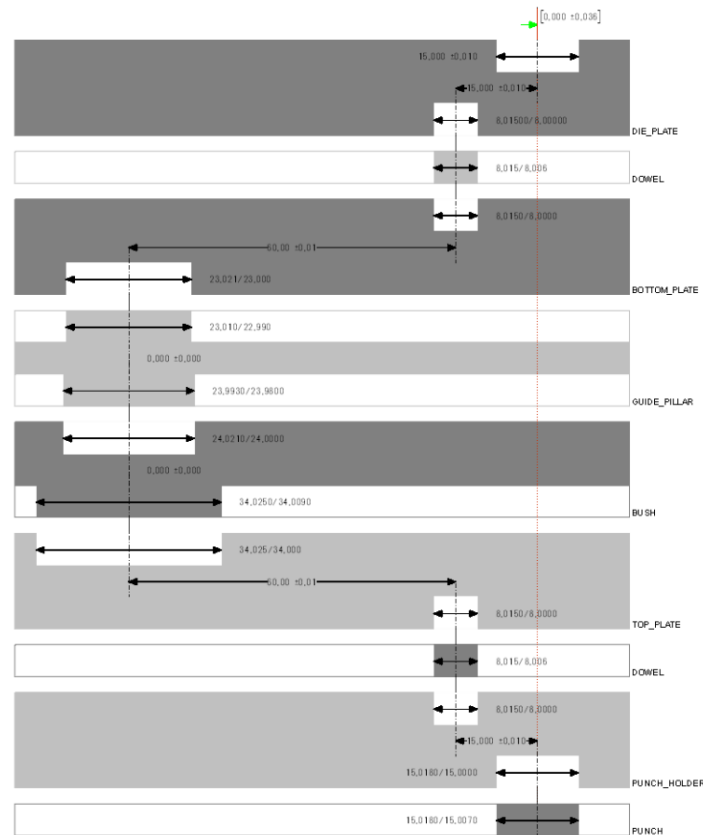
## IV. RESULT & DISCUSSION

### A. CAD Tolerance Analysis for zero mm variation in punch and die

The variation plot shown the worst-case range and statistical distribution for the measurement. The measurement specification limits and the target value are user-specified values. These define the design requirements for the measurement. Since in this Study the measurement target value is zero. Here yield percentage is zero with zero measurement target value (see Figure 5). It is not possible to assemble a press tool with zero variations in between punch and die. See figure 6 for dimension and their loop diagram for contribution in stackup analysis. Tolerance assigned for dimension is taken from the die design standard hand book[30].

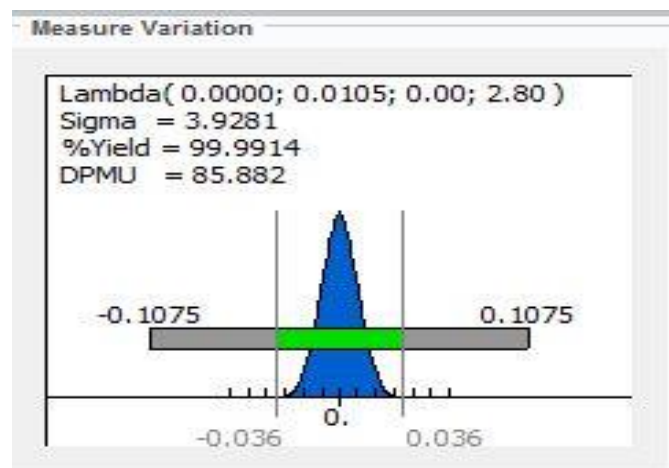


**Figure 5 A variation plot For Zero measurement target value**



**Figure 6 Dimension loop diagram**

According to six sigma approach the measurement target value increased to .036. The yield percentage increased to 99.9914% with 85.882 DPMU. Here statistical variation calculated by Software is 0.036 mm which is closed to  $t_{RSS}$ . See figure 7.

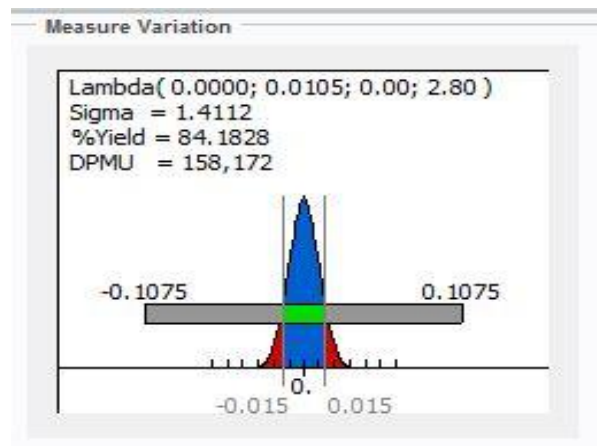


**Figure 7 A variation plot For 99.99 percentage of yield**

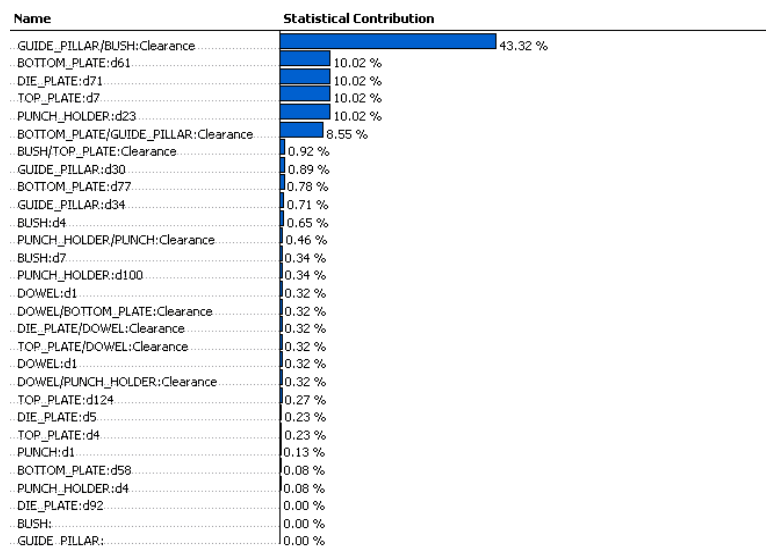
**B. Tolerance allocation to press tool part to maintain minimum clearance zone .015mm per side**

From minimum clearance zone calculation. The variation in between die and punch should be 0.015 mm per side. For this measurement target value, the yield

percentage dropped to 84.1828(see Figure 8) with increase DPMU to 158,172. To increase the Yield percentage and decrease the DPMU tolerance reallocated to the dimension on the basis of percentage contribution. See Figure 9 for the contribution of dimension and their tolerances in assembly variation.



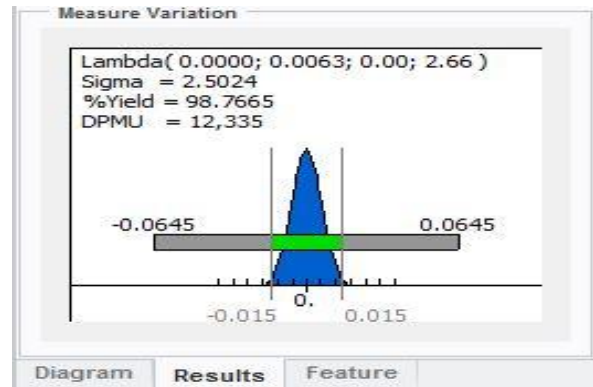
**Figure 8 A variation plot against 0.015mm. Per side**



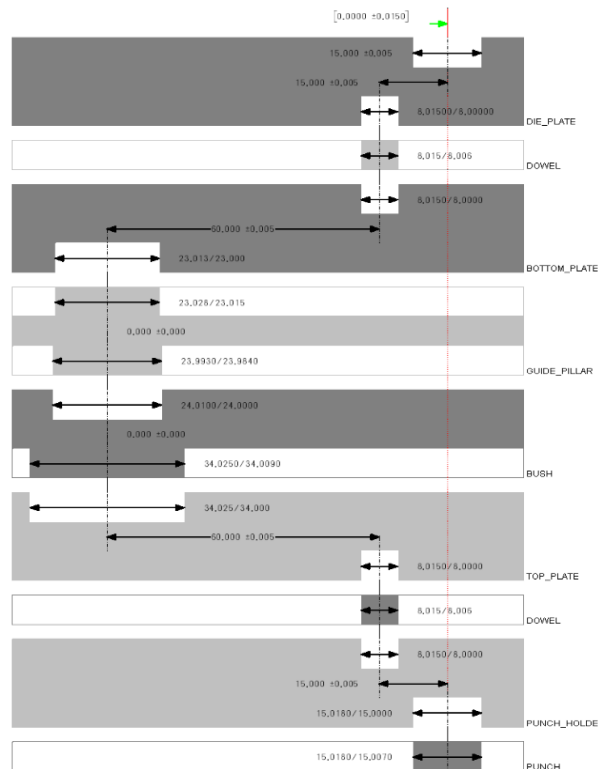
**Figure9 Percentage contribution of dimension in variation of assembly**

After reallocation of tolerance iteratively and simulated the assembly, yield percentage increased to 98.76 see figure 10. Allocation of tolerance for dimension was done on the basis of process capabilities of machine

available in manufacturing industries. See the figure 11 for new tolerance associated with loop dimension in stackup analysis.



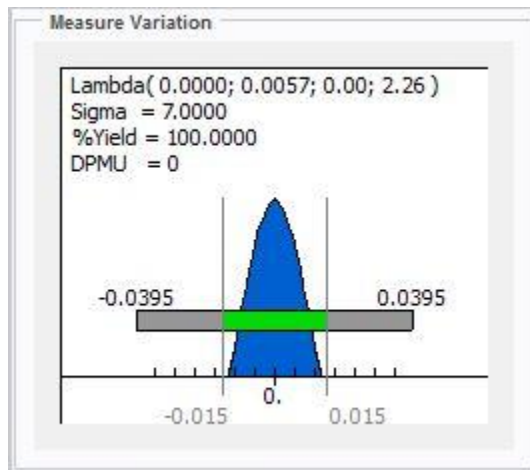
**Figure 10 A variation plot against 0.015mm per side after reallocation of tolerance for dimensions**



**Figure 11 Dimension loop diagram after reallocation of tolerance for dimensions**

Position geometric control for the hole in plates represent better functionality [33]. Greater Percentage contribution of tolerance increases variation of assembly. By Iterative tolerance allocation to the parts of the yield percentage achieved to 100 percentage (see Figure 12). Without affecting Functionality of the parts.

Conventional Position tolerance changed to geometrical position tolerance with cylindrical tolerance zone with better functionality. During simulation diameter .005mm position tolerance was assigned to all plates in upper half and lower half of the die assembly.



**Figure 11 variation plot with 100 yield percentage**

## V. CONCLUSION

1) This study suggest that Clearance between guide bush & guide pillar is more responsible for the variation in Die & Punch alignment. It is not necessary to always select H7/g6 Fitment. Fundamental deviation H & g for hole & shaft respectively basically achieve the functionality i.e. clearance fit. IT grade decided according to manufacturing process, capability of machine, Tonnage capacity of tool

2) From the Fundamental deviation & IT grade table it is evident that as the size of Hole & shaft will increases the value of deviation & IT grade for that particular dimension will also increase. Thus limit of size of the dimension will increase that will cause more variation in assembly.

3) There are two method that has used in this Study for Stack up analysis. Worst case method suggest that component will always produce at their extreme limit of dimension. For the mass production it is not possible to consider design on the worst dimensional approach. It is applicable for the assembly have less number of component to assemble. Statistical approach which consider the distribution of

manufactured dimension within the limit of size. It is applicable for assembly having large Number of component to assemble. Acceptability of the assembly depend upon the Standard deviation of the manufacturing process.

4) Use of GD&T increase the acceptability of machined part since increase the area of tolerance Zone in comparison to Conventional tolerancing System.

5) CETOL Analysis software used to perform tolerance analysis and tolerance allocation simultaneously. Tolerance has allocated on the basis of manufacturing capability of machine & percentage contribution of dimension that contribute more in variation of assembly. Assembly had simulated number of time to get optimum result that had suggested in Journal

[5] results from number of experiment. During design process design engineer can easily assign the optimum tolerance to press tool parts.

6) Use of software for tolerance allocation will give a full proof design. Ultimately it will reduce the number of trials

and rework of the tool to get good quality stamped component.

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