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OPTIMIZATION OF ASSEMBLY GAP TOLERANCE USING MONTE CARLO METHOD AND SELECTION OF OPTIMAL TOLERANCE METHOD

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Abstract: The tolerancing concept is essential in part design process. It describes a relation between the many stages of the design and manufacturing activities. In this paper, tolerance models were developed to estimate required tolerance gap of selected assembly parts using python programming. The Monte Carlo Method is selected and using Uniform and Normal Distributions for finding required tolerance gap for given assembly.

Index Terms - Part Assembly, Tolerance Gap, Monte Carlo Method, Python.

I. INTRODUCTION

Tolerance refers to the allowed variation in measurements derived from the base measurement. Tolerances are divided into three categories [1]: Unilateral, Bilateral and Compound tolerances. Unilateral tolerances consist of two limit dimensions that are simply above or below the normal size, whereas bilateral tolerances consist of two limit dimensions that are both above and below the nominal size [1]. Compound tolerances are a combination of more than one form of tolerance; the multiple types of tolerances can include angular, lateral, and other sorts of tolerances. For this work, the bilateral tolerances are taken into account. Gaps would be created while assembling the parts of an assembly; the Monte Carlo method is used to optimize that gap tolerance and is implemented in Python [3].

- An infinite number of assembly part tolerances and gap tolerances are generated within the tolerance range by optimizing the tolerances [2].
- Tolerances of different models are compared each other and represents optimal method [1].

II. METHODOLOGY

In order to obtain the ‘n’ sample of random values of each part and gap tolerances of part assembly, Monte Carlo method is used, which involves the probability distribution to generate random values of assembly parts [2]. To generate random values, this work considers Normal and Uniform distributions and those methods are implemented in the Python programming. The Monte Carlo method is used for finding optimal solutions. By adopting this methodology, the low possibility of getting errors in assembly occurred [4].

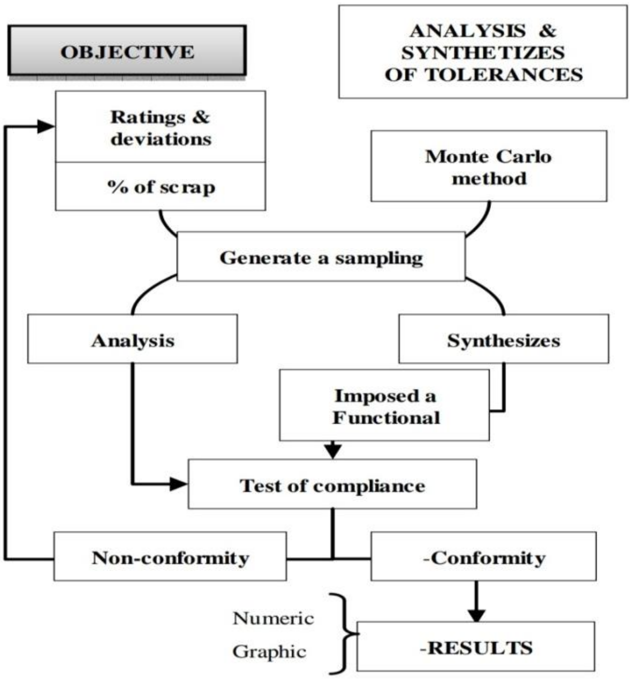


Fig1. Monte Carlo Algorithm

The obtained results from the normal distribution and uniform distribution are observed and compared, between the two methods the optimal method selected for generating 'n' sample of random values of tolerances of the assembly.

III. EXPRESSION FOR UNIFORM AND NORMAL DISTRIBUTIONS

(i) Uniform distribution

Uniform distributions are probability distributions in which all events are likely equal. The probability density function [3],

$$f(x) = \begin{cases} \frac{1}{b-a} & \text{for } a \leq x \leq b \\ 0 & \text{for } x < a \text{ or } x > b \end{cases}$$

Where 'a' is minimum value and 'b' value is maximum value

$$\text{Mean } (\mu) = \frac{(a+b)}{2}$$

$$\text{Standard Deviation } (\sigma) = \sqrt{\frac{(b-a)^2}{12}}$$

(ii) Normal distribution

Normal distribution (Gaussian distribution) is a symmetric probability distribution around the mean, indicating that data near the mean occur more frequently than data far from it. The probability density function [4],

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}(\frac{x-\mu}{\sigma})^2}$$

$$\text{Mean } (\mu) = \frac{(a+b)}{2}$$

$$\text{Standard Deviation } (\sigma) = \frac{Tolerance}{3}$$

IV. CASE STUDY

The figure 4.1 is considered and the methodologies described in this work are used to generate the tolerance for the assembly gap [5].

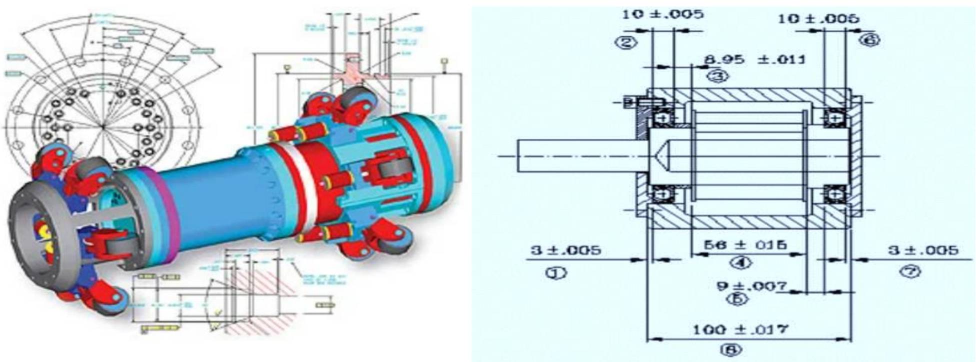


Fig 4.1 Mechanical Motor Assembly

Part 1(A) and 2(B) = 10± 0.005
Part 3(C) = 8.95 ± 0.011
Part 4(D) = 56 ± 0.015
Part 5(E) = 9 ± 0.007
Part 6(F) and 7(G) = 3 ± 0.005
Part 8(H) = 100 ± 0.017

Here, the dimensions of part 1, 2, 4,5,6,7 are fixed dimensions and 3 and 8 are variable dimensions and their values calculating by using tolerancing methods.

4.1 MODELING OF TOLERANCE BY USING MONTE CARLO METHOD

Gap = H - (A+B+C+D+E+F+G) (eq.1)

Total Tolerance (TT) = $3 * \sqrt{(SD_A)^2 + (SD_b)^2 + \cdots + (SD_H)^2}$ (eq.2)

Gap $_{(max)}$ = H - (A+B+C+D+E+F+G) + TT (eq.3)

Gap $_{(min)}$ = H - (A+B+C+D+E+F+G) -TT (eq.4)

According to the eq.1, eq.2, eq.3 and eq.4, the following table represents Mean, Standard deviation and Total Tolerance of Normal distribution and Uniform distribution for each part of the mechanical assembly.

Table1. Values of Mean and Standard deviation

	NORMAL DISTRIBUTION		UNIFORM DISTRIBUTION	
PART	**MEAN (μ)**	**SD (σ)**	**MEAN (μ)**	**SD (σ)**
A	10	0.0016	10	0.0028
B	10	0.0016	10	0.0028
C	8.95	0.0036	8.95	0.0063
D	56	0.0050	56	0.0086
E	9	0.0023	9	0.0040
F	3	0.0016	3	0.0028
G	3	0.0016	3	0.0028
H	100	0.0056	100	0.0098
Total Tolerance	0.0280		0.3240	
Gap $_{(max)}$	0.3740			
Gap $_{(min)}$	0			

These values are taken as inputs for generating the tolerances of each part and gap tolerance of the mechanical assembly in the Python according to the Normal distribution and Uniform distribution of Monte Carlo method.

V. RESULTS AND DISCUSSIONS

According to the chapter III, the python code for the Tolerancing Methods of Monte Carlo Method is implemented and the assembly tolerances are generated by using Normal Distribution and Uniform Distribution and their results are,

Output of the Uniform distribution

Table2. Tolerance Values of the assembly parts

```
List of the random numbers of part-A :
   RANDOM VALUES 1  RANDOM VALUES 2  RANDOM VALUES 3  RANDOM VALUES 4
0         9.999656         9.996441        10.000785        10.001392
1         9.999416         9.999342        10.002058         9.997893
2        10.001789        10.000599        10.000029         9.997775
3        10.002193        10.001998         9.998240        10.001246
4        10.002297        10.000901        10.004041        10.002364
5        10.003487         9.997433        10.001477         9.999157
6        10.000914         9.998799        10.000344        10.001352
7         9.999557         9.996574         9.999667         9.999856
8        10.001031        10.001988         9.998069         9.999726
9         9.998851        10.001353         9.999716        10.001349

List of the random numbers of part-B :
   RANDOM VALUES 1  RANDOM VALUES 2  RANDOM VALUES 3  RANDOM VALUES 4
0         9.999320         9.999986        10.001486         9.999952
1        10.002902        10.000241         9.998559        10.001477
2         9.999853         9.997744         9.998897         9.997652
3         9.998798        10.002488        10.001370        10.000805
4         9.999781        10.002234         9.997632         9.998384
5        10.001448         9.998174         9.997497         9.999654
6         9.997101        10.004268         9.999529        10.003766
7        10.000673         9.998080         9.998243        10.000180
8        10.000828        10.000179        10.002350        10.001947
9        10.000994        10.000878        10.001245        10.001341
```

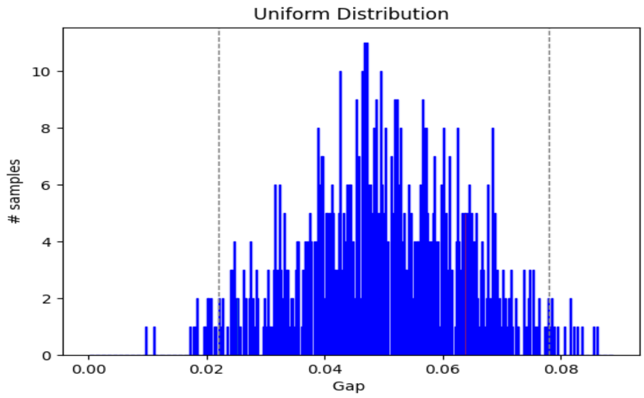
Similarly, random values generated for part-C to part-H and the Gap tolerances of assembly,

Table 3. Tolerance values of the Gap

Gap :

	RANDOM VALUES 1	RANDOM VALUES 2	RANDOM VALUES 3	RANDOM VALUES 4
0	0.044846	0.067387	0.048068	0.041381
1	0.047303	0.053572	0.033874	0.055084
2	0.044421	0.049727	0.037238	0.075008
3	0.047350	0.028257	0.060032	0.043299
4	0.031725	0.053757	0.064774	0.053111
5	0.060848	0.048421	0.048607	0.060496
6	0.043630	0.051837	0.048499	0.041735
7	0.053991	0.058472	0.032252	0.055657
8	0.037513	0.061448	0.055302	0.044282
9	0.051521	0.038852	0.054005	0.033443

Graph



The graph represents the relation between the Gap on X-axis and no. of samples on Y-axis and grey vertical lines represents lower limit and upper limit of gap. The samples outside of grey vertical lines are failures.

Output of the Normal distribution

Table4. Tolerance Values of the assembly parts

List of the random numbers of part-A :

	RANDOM VALUES 1	RANDOM VALUES 2	RANDOM VALUES 3	RANDOM VALUES 4
0	9.998154	10.000955	9.999342	10.004538
1	10.004507	9.995699	10.001203	9.995915
2	9.996037	9.998187	10.001552	9.999555
3	10.002420	10.003879	9.998409	10.001128
4	10.000202	10.001693	10.002582	10.002520
5	9.996737	9.996574	10.001243	9.995903
6	10.002300	9.995277	10.004225	9.998242
7	10.001001	9.999753	9.998898	9.995621
8	10.000377	9.999915	10.000210	10.004247
9	10.004839	9.996455	9.998029	10.000825

List of the random numbers of part-B :

	RANDOM VALUES 1	RANDOM VALUES 2	RANDOM VALUES 3	RANDOM VALUES 4
0	9.998869	9.998361	9.997954	9.995241
1	9.999078	9.995465	10.002567	9.999037
2	10.001395	9.995966	9.997386	10.001937
3	9.998392	9.997545	9.995504	10.001812
4	9.995836	10.002574	10.002284	9.995832
5	10.004261	10.003403	10.003413	9.997449
6	9.998431	10.002518	10.000481	9.999496
7	9.995472	10.002736	10.003321	10.003220
8	10.003426	10.002352	10.001342	9.997838
9	10.000189	10.002725	10.000412	10.004206

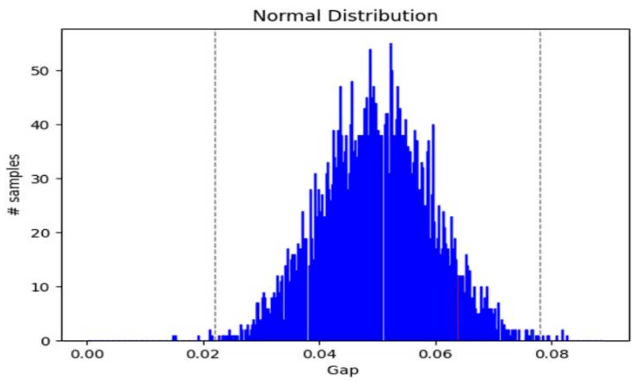
Similarly, random values generated for part-C to part-H and the Gap tolerances of assembly,

Table 3. Tolerance values of the Gap

Gap :

	RANDOM VALUES 1	RANDOM VALUES 2	RANDOM VALUES 3	RANDOM VALUES 4
0	0.051925	0.022732	0.065607	0.063674
1	0.043316	0.030390	0.042026	0.053369
2	0.029901	0.025986	0.058736	0.039508
3	0.056028	0.014480	0.076607	0.048720
4	0.036657	0.086656	0.043816	0.054748
5	0.051212	0.059440	0.030503	0.033895
6	0.067492	0.006559	0.061152	0.074807
7	0.043243	0.042211	0.058699	0.049119
8	0.057554	0.046010	0.032875	0.034287
9	0.058019	0.035598	0.033337	0.070574

Graph



The graph represents the relation between the Gap on X-axis and no. of samples on Y-axis

VI. COMPARISON BETWEEN THE UNIFORM AND NORMAL DISTRIBUTIONS

The mean and standard deviation are the inputs for uniform and normal distributions. And also, lower and upper limits are considered as inputs for uniform distribution. By comparing the values of both the distributions, it is observed that the rejection rate of the assembly of normal distribution is less than the uniform distribution. It is found that the estimated values of tolerance gap are very low in normal distribution.

VII. CONCLUSION

The optimal tolerance gaps were estimated for given assemblies to minimize the defects like rework and rejection of the machine parts. Values of both distributions are compared; So that the normal distribution is considered as optimal tolerance method.

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