ARTIFICIAL NEURAL NETWORK BASEDTOLERANCE ANALYSIS METHOD[1]

***A. Maria Jackson, **Dr. R. Panneer**

**M. Tech (Advanced Manufacturing), **Associate Professor*

Sastra University, School of Mechanical Engineering, Tanjore, Tamil Nadu, India

ABSTRACT

The following four Tolerance Analysis methods were identified for comparative analysis, critical study and investigation based on the significance of the methods and also considering the versatility of the methods.

(i) SIMULATION BASED STACK-UP ANALYSIS,

(ii) SECOND ORDER TOLERANCE ANALYSIS,

(iii) OpTol - SPATIAL TOLERANCE ANALYSIS,

(iv) TOLERANCE ANALYSIS OF 2D AND 3D ASSEMBLIES.

The Literature relevant to the selected methods were critically studied and compiled. Upon gathering further information on the advantages and limitations of these four methods, a framework for the new method will be developed overcoming the problems found in existing methods. Artificial Neural Network will be used to overcome most of the problems found.

***Keywords** – Tolerance Analysis; Simulation; Spatial Tolerance Analysis; Artificial Neural Network.*

INTRODUCTION

Tolerance is the total amount that a specific dimension is allowed to vary. Every product is designed with tolerance limits because it is difficult to manufacture component to its exact dimensions because of chance causes and assignable causes of errors. Tolerance is a common arguable point between design and manufacturing. Design Engineer tries to tighten the tolerance for better functionality of the product, whereas Production Engineer tries to relax it for better utilization of resources.

As manufacturing companies pursue higher quality products, they spend much of their efforts in monitoring and controlling variations. One of the effective tools for variation management is TOLERANCE ANALYSIS. The understanding of tolerance analysis is importance because it is the criteria between two important factors COST and FUNCTION of the product to be manufactured. Tolerance analysis also called Stack-up analysis is one of the effective tools of variation management is tolerance analysis. This is a quantitative tool for predicting the accumulation of variation in an assembly by performing a stack-up analysis.

[1] How to cite the article:
Jackson A.M., Panneer R., Artificial Neural Network Based Tolerance Analysis Method; *International Journal of Advances in Engineering Research*, June 2014, Vol 7, Issue 6, 25-36

METHODOLOGY

As tolerance plays a vital role in success of a industry, it is essential for an Industrial Engineer to understand the world of tolerance. Various methods (about 15) on Tolerance Analysis has been collected for study purposes. Upon study, they are classified into four major types, namely,

- Monte Carlo Simulation (random number for probability distribution)
- Non Linear Propagation (Development of models to establish relationship function)
- Computer Aided Tolerance Analysis (Use of a computer software which has a database of Tolerances).
- 2D and 3D analysis (Creation of vector loops)

Upon study of the above listed methods in detail, a critical investigation on every method has been made and the problems found in every method were listed. Advantages and disadvantages of the methods, one over the other have been identified. After compilation of the listed methods, a framework for the development of a new method will be suggested. The complete process is shown in figure 1 as a flowchart.

Figure 1: Methodology of the paperwork

INVESTIGATION RESULTS

(i). Number of iterations are variable and it depends on required accuracy level of simulation. Part representation is complex and it depends on size and locations of the sample points. Simulation has its own advantages and disadvantages.

(ii). As quality levels increases sample size increases 100 times. Level of information required for computation of component tolerance and distribution is high.

(iii). Worst case Tolerance Analysis is rarely encountered in actual manufacturing. Models are assumed to have normal distribution which is not reflected in real conditions.

(iv). Difficulty increases along with the number of chains or loops or chains formed. Evaluation of the vector loop is not discussed.

FRAMEWORK PROPOSAL

A new framework with the objective of overcoming the deficiencies is the objective of the work. As far discussed Simulation is one of the most used yet a deficient step made in tolerance analysis. Artificial Neural Network is the tool proposed here instead of Simulation. Input (Component)tolerances are collected for a particular assembly and functional relationship between input and output assembly tolerances has to be established.

STEP I: For a chosen assembly create the vector loops as stated by Kenneth W. Chase. And find the critical assembly dimension among a particular loop.

STEP II: Now for the number of dimensions and it's nominal value along with the tolerance values in the particular loop has to be listed.

STEP III: Using Taguchi's Orthogonal Array construct the table of parameter and response. Vector loop dimensions are parameters with its respective tolerance values as three levels (namely upper, lower and middle values) and closing dimension of vector loop which is the critical dimension of the assembly's tolerance values is the response of the design. Using Geometric Interpolation the responses can be found using design software.

STEP IV: Construction of Artificial Neural Network (ANN) with the collected information as Training data which is further tested for known values. Now the ANN can be used for finding Assembly tolerance for changes can be made in component dimension tolerances.

VECTOR LOOP GENERATION

Vector loop generation is explained in steps considering the following assembly shown below in figure 2.

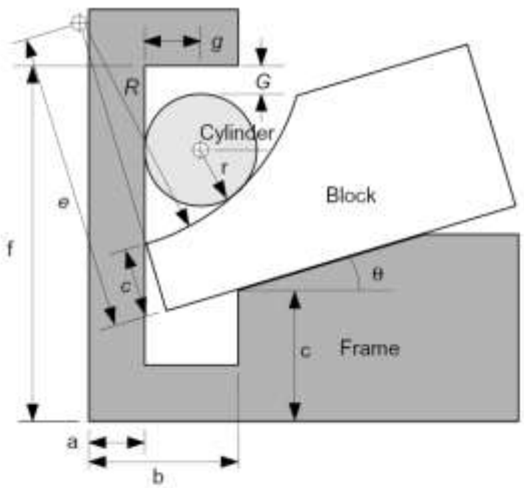


Figure 2: Stacked blocks assembly.

(a) Firstly, create an assembly graph which is a simplified diagram of assembly without any dimensions as in figure 3. It shows the mating conditions between the parts.

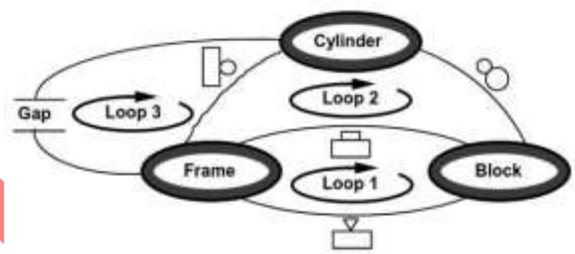


Figure 3: Assembly graph of stacked blocks assembly.

(b) Location of DRFs shown in figure 4. The first elements added are a set of local coordinate systems, called Datum Reference Frames, or DRF. Each part must have its own DRF. The DRF is used to locate features on a part.

(c) Locate kinematic joints and datum paths. A datum path is a chain of dimensions which locates the point of contact at a joint with respect to a part DRF. Datum paths of the considered assembly is shown in figure 5.

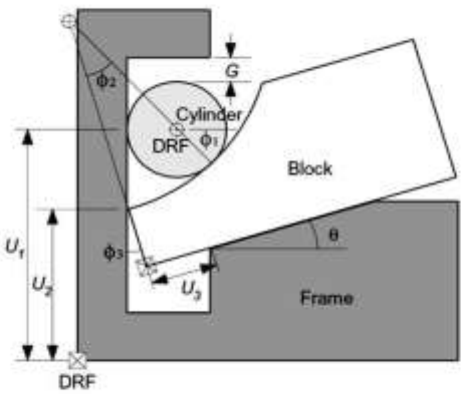


Figure 4: Datum Reference points.

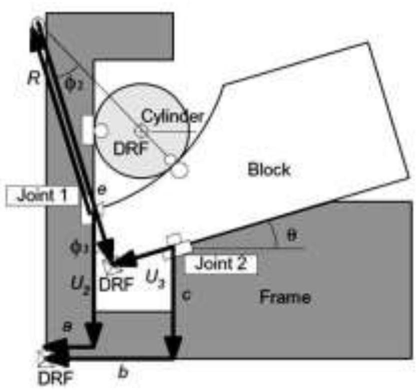


Figure 5: Datum paths for Joints 1 and 2

(d) Modeling rules, Enter through a joint, follow the datum path to the DRF, follow second datum path leading to another joint, exit to the next adjacent part in the assembly as in figure 6.

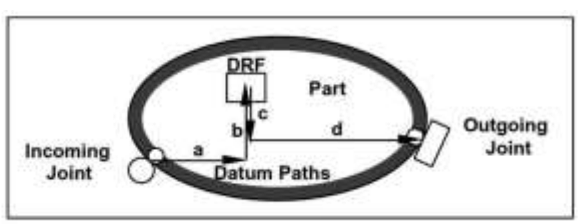


Figure 6: Modeling rules.

NEW METHOD OF TOLERANCE ANALYSIS

For the new method the assembly considered is shown below in figure 7.

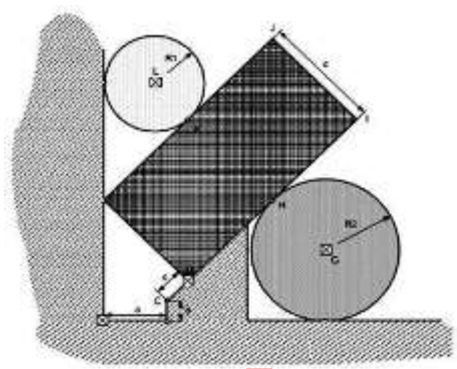


Figure 7: Assembly model considered.

Various loops formed in the assembly are shown in figure 8.

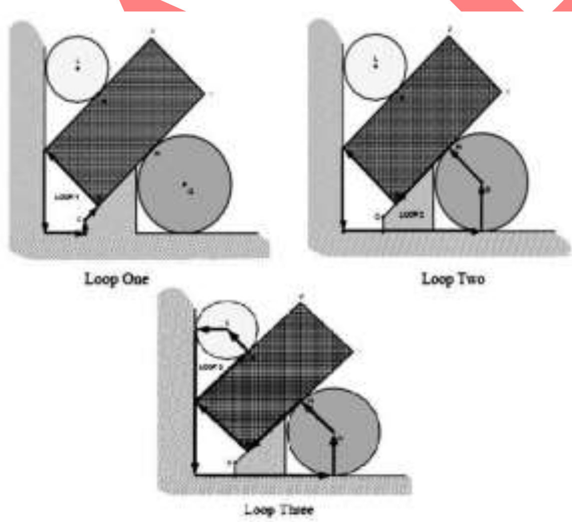


Figure 8: Various loops formed.

The component coordinates from vector loop data and their input tolerances are listed belowin table 1 and table 2 respectively..

Table 1: Points and their coordinates of the assembly considered

Poi	A	B	C	D	E	F	G	H	K	L	M
X	0	3	3	4	0	10.	10.5	8	4	2.4	0

Table 2: Loop segments and their respective tolerance value

LOOP I			LOOP II			LOOP III		
Name	Tol- Mm	Tol+ mm	Name	Tol- mm	Tol+ mm	Name	Tol- mm	Tol+ mm
AB	-0.02	0.05	AF	-0.02	0.02	AF	-0.02	0.02
BC	-0.02	0.01	FG	-0.05	0	FG	-0.05	0
CD	-0.1	0.01	GH	-0.01	0.01	GH	-0.01	0.01
EA	-0.03	0.04	HD	-0.01	0.01	HD	-0.01	0.01
			DE	-0.05	0.05	DE	-0.05	0.05
			EA	-0.01	0.04	EK	0	0
						KL	0	0
						LM	0	0
						MA	-0.02	0.05

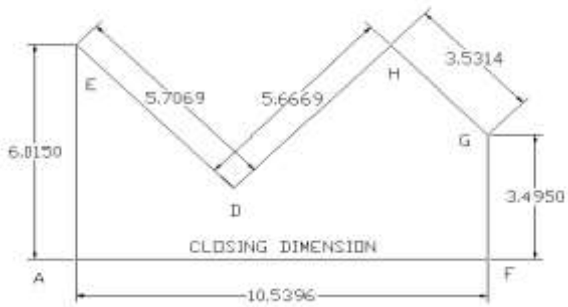
Loop 2 is chosen and the number of contributing dimensions is found to be five, such as AE, ED, DH, HG, and DF for the closing dimension AF, which is one of the assembly dimensions for the model considered. With the five component dimensions as parameters and the tolerance values as three levels (upper, middle, and lower values). The parameter and its three levels are listed below in table 3.

Table 3: Component's nominal value and various levels of tolerances

Component & nominal	Lower level	Middle level	Higher level
AE 6	-0.01	0.015	0.04
ED 5.6569	-0.05	0	0.05
DH 5.6569	-0.01	0	0.01
HG 3.5214	-0.01	0	0.01
GF 3.52	-0.05	-0.025	0

(All units are in mm)

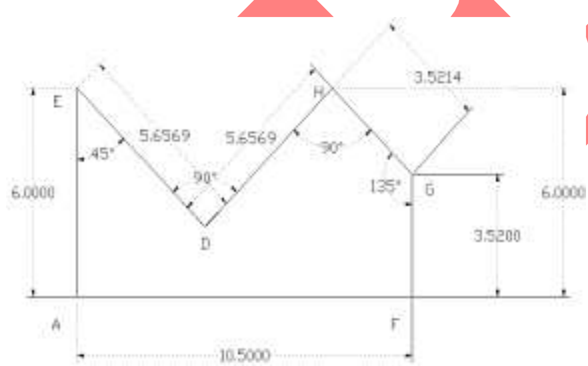
Nominal values are found from AutoCAD model as shown in figure 9 (Screenshot of AUTO CAD).



(All units are in mm)

Figure 9: Loop 2 drawn using AutoCAD without tolerance.

Using Taguchi's Orthogonal Array for four parameter three levels, L27 is chosen. To find the response that is closing dimension of the loop by using geometric interpolation of the coordinates and an model interpolation is shown in figure 10.



(All units are in mm)

Figure 10: 16th run CAD model diagram for interpolation

Final tabulation of L27 with observation of critical dimension using geometric interpolation is listed table 4 below.

Table 4: Final tabulation of interpolated value of critical dimension

S. No	FG 3.52	GH 3.5214	HD 5.6569	DE 5.6569	EA 6	AF (Critical Dimension) 10.52
1	-0.025	0	-0.01	0.05	-0.01	+0.0074
2	-0.025	-0.01	0.01	-0.05	0.04	-0.0648
3	-0.05	0	0.01	-0.05	0.015	-0.0582
4	0	0.01	-0.01	0	-0.01	-0.0299
5	-0.05	-0.01	-0.01	-0.05	-0.01	-0.0667
6	-0.05	0.01	0	-0.05	0.04	-0.0577
7	0	0	0	0	0.04	-0.0299
8	-0.05	0.01	0.01	0	0.04	-0.0155
9	-0.05	-0.01	0.01	0.05	-0.01	0.0127
10	0	0	-0.01	-0.05	0.04	-0.0722
11	0	0.01	0.01	-0.05	-0.01	-0.0441
12	-0.05	0	-0.01	0	0.015	-0.0369
13	-0.025	-0.01	-0.01	0	0.04	-0.0439
14	0	0.01	0	0.05	-0.01	0.0226
15	-0.05	-0.01	0	0	-0.01	-0.0307
16	-0.025	0.01	0.01	0.05	0.015	-0.0196
17	0	-0.01	0.01	0	0.015	-0.0299
18	0	0	0.01	0.05	0.04	0.0125
19	-0.025	-0.01	0	0.05	0.04	-0.0016
20	0	-0.01	0	-0.05	0.015	-0.0722
21	-0.025	0	0	-0.05	-0.01	-0.0591
22	-0.05	0.01	-0.01	0.05	0.04	0.0055
23	-0.05	0	0	0.05	0.015	0.0054
24	-0.025	0	0.01	0	-0.01	-0.0157
25	-0.025	0.01	0	0	0.015	-0.0228
26	-0.025	0.01	-0.01	-0.05	0.015	-0.0642
27	0	-0.01	-0.01	0.05	0.015	-0.0087

(All units are in mm)

ARTIFICIAL NEURAL NETWORK

The neural fitting tool (nftool) in Matlab shown in figure 11 is chosen for creating and training the neural network. In nftool window the collected data of component dimensional tolerances as input data and interpolated output dimensional tolerance as output data were fed in excel sheet format. Validation and test data is divided up here in 15% each where the rest 70% of data is used for training the network.

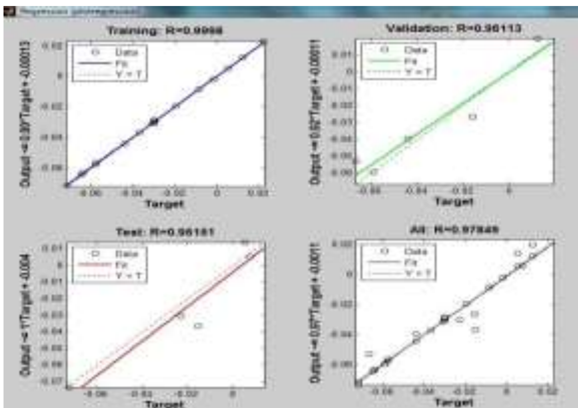


Figure 11: Neural Network fitting tool screenshot.

In network architecture number of hidden neurons was selected by trial and error for better result. Here 10 neurons were chosen. Neural network was created in the next step which has to be trained further. Trained network is plotted for regression in which all the R value has to be closer to one, otherwise retrained. Regression plot of the trained network is shown in figure 12.

Figure 12: Screen shot of Regression Analysis after training.

Data are saved and the Simulink diagram was created. In the Simulink diagram the input data were fed for known component dimensional tolerance from which the output assembly tolerance values are generated using the trained neural network. Figure 13 shows the screenshots of Simulink diagram and input parameter blocks.

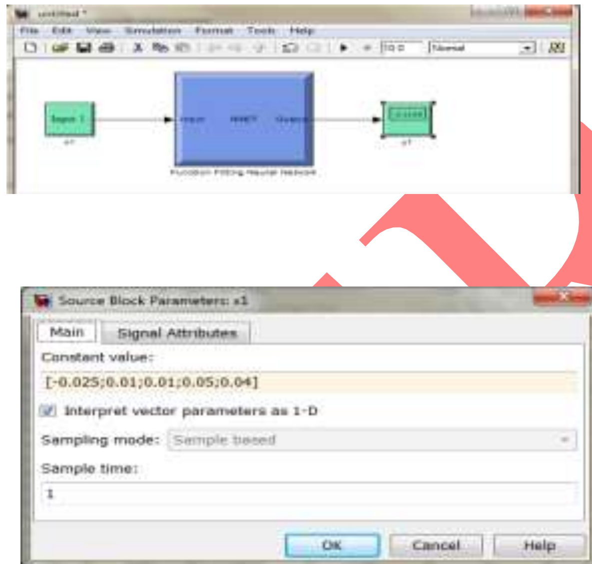


Figure 13: Screenshot of Simulink diagram.

CONCLUSION

Frame work of a Tolerance Analysis method which uses the vector loop closure integrated with the Artificial Neural Network is developed. This method eliminates the Simulation procedure which is found as one of the problems in present industrial world of Tolerance Analysis.

This framework is being developed into a complete method using real industry data for an assembly and used as the training data for Artificial Neural Network.

REFERENCES

[1] Rami A. Musa, (August 2003); Simulation-Based Tolerance Stackup Analysis in Machining; University of Cincinnati, August, 2003.

[2] Charles. G Glancy; (Dec 1994); Second - Order Method for Tolerance Analysis; *ADCATS*Report no 94-5.

[3] Karoly Nehez, (2009); OpTol: Spatial Tolerance Analysis; Production Systems andInformation Engineering, Volume 5, pp. 109-138.

[4] Chase, K.W., .(1999), Tolerance analysis of 2-D and 3-D Assemblies., *ADCATS*, Report no

99-4.

[5] Fritz Scholz, Research and Technology Boeing Information & Support Services, Tolerance Stack Analysis Methods, December 1995.

[6] K.G. Merkley, K.W. Chase, *An Introduction to Tolerance Analysis;* E. Perry Brigham Young University Provo, UT.

[7] Jirarat, Teeravaraprug, (12 Feb 2007); A Comparative Study of Probabilistic and Worst-case Tolerance Synthesis; Advance online publication, *Engineering Letters* 14:1, EL_14_1_5.

[8] Polini, Wilma, (4 October 2010); A review of two models for tolerance analysis of an assembly: Jacobian and Torsor; *International Journal of Computer Integrated Manufacturing*; TCIM-2009-IJCIM-0119.R2

[9] Constantinos Mavroidis, AReview Of Tolerance Analysis Of Mechanical Assemblies; Department of Mechanical and Aerospace Engineering, Rutgers University.

[10] Kenneth W. Chase, Alan R. Parkinson, (5 April 1991); A Survey of Research in the Application of Tolerance Analysis to the Design of Mechanical Assemblies; *Research in EngineeringDesign* 3:23-37.

[11] E. E. Lin and H.-C. Zhang, (2001); Theoretical Tolerance Stackup Analysis Based on Tolerance Zone Analysis; *Int J Adv Manuf Technol;* 17:257–262.

[12] Gene R. Congano, (2006), Geometric Dimensioning and Tolerancing for Mechanical Design, McGraw-hill

[13] American Society for Quality, (1986); How to perform statistical Tolerance Analysis?", Volume 11, ISBN 0-87389-010-8.

[14] Chase, K. W., and W. H. Greenwood, (1988); Design Issues in Mechanical Tolerance Analysis,. *Manufacturing Review*, ASME, v 1, n 1, pp. 50-59, March.

[15] Ken Chase, "Basic tools for Tolerance Analysis of mechanical Assemblies" Brigham University, Provo, Utah.