MANUFACTURING TOLERANCE DESIGN BASED ON FUZZY BINARY APPROACH

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ABSTRACT

In this paper, the concept of binary, fuzzy systems has been applied. These concepts optimize tolerance as a percentage through the fuzzy approach (based on binary values 0 and 1). Finally, the tolerance fit into six different levels along with optimized cost has been characterized, namely, best fit with minimum cost, better fit with minimum cost, good fit with minimum cost, acceptable range for minimum required fit with minimum cost, non acceptable range, and worst fit range.

Keywords: tolerance; fit; critical dimensions; fuzzy analysis; binary approach; optimum solutions.

TOLÉRANCE DE FABRICATION BASÉE SUR L'APPROCHE LINÉAIRE FLOUE

RÉSUMÉ

Dans cet article, le concept de systèmes binaires flous est appliqué. Ces concepts d'optimisation de la tolérance s'expriment en tant que pourcentage par l'approche floue (basée sur les valeurs binaires 0 et 1). L'ajustement de la tolérance se caractérise dans six niveaux différents, et l'optimisation des coûts a été définie, soit l'ajustement optimum à un coût minimum; le meilleur à un coût minimum; le bon à un coût minimum; l'intervalle acceptable pour l'ajustement minimal requis à un coût minimum; un intervalle non acceptable; et le plus mauvais des ajustements.

Mots-clés : tolérance; ajustement; dimensions critiques; analyse floue; approche binaire; solution optimale.

NOMENCLATURE

X	critical dimension (CD) (in %)
L_1	major dimension of part 1 (MD) (in %)
L_2	subassembly dimension of part 2 (in %)
L_3	subassembly dimension of part 3 (in %)
L_4	subassembly dimension of part 4 (in %)
L_n	subassembly dimension of part n (in %)
d	major clearance limit in [0, m]
m	input value

1. INTRODUCTION

Quality is a characteristic of good design. The robustness of products is more a function of good design than of online control. However, it is difficult to achieve. Indeed an inherent lack of robustness in product design is the primary driver of superfluous manufacturing expenses. Robust design practices can lead to lower cost, improvements in quality, manufacturability and reliability. At present the assignment of design tolerances is performed largely on a trial and error basis using the tolerance analysis method as recommended by Chase and Greenwood [1]. Thus tolerance design is a vital issue in product development.

Design of tolerance is one of the significant roles in product design and development process as it affects both the functional requirements of product and manufacturing cost.

Tolerances have a significant impact on manufacturing cost and product quality. Traditional methods for tolerance analysis and synthesis are time consuming and have limited application. A more systematic approach is often desirable for better performance to overcome this difficulty. The objective of this paper is to examine optimal tolerance allocation by using fuzzy binary approach. The amount of variation permitted for the basic size is called tolerance.

Conventional tolerance analysis is complicated and time consuming whereas complex assembly problems are normally beyond the capabilities of most design and manufacturing engineers. Tolerance synthesis is based on optimization. The relatively new and sometimes popular technique known as fuzzy logic is used to determine optimized cost.

1.1. Fit and Tolerance

When two parts are to be assembled, the relation resulting from the difference between their sizes before assembly is called a fit. A fit may be defined as the degree of tightness and looseness between two mating parts. The important terms related to the fit are given below according to Chase and Greenwood [1]:

(i) Clearance Fit.

(ii) Interference Fit.

(iii) Transition Fit.

1.2. Definitions

- Limit: Permissible size or acceptable size.
- Fit: The degree of tightness or looseness between two mating parts.
- Clearance: The positive difference between sizes of the gap dimension and its assembly part dimension.

Table 1. Selection based on application of fit.

Sl.No	Type of Fit	Application Fit	Application
1	Clearance	Slide fit	Pulleys, Slider piston cylinder assembly, Gear assembly, etc.
2	Interference	Force fit	Rims, Car wheels, Fixed joints, etc.
3	Transition	Push fit	Railway wheels, Fixing keys, Pins, Lock system, Valves, etc.

- Interference: The negative difference between sizes of the gap dimension and its assembly part dimension.

- Transition: It is tolerance zone where the gap dimension and its assembly part dimension overlap.

- Tolerance: The permissible variation in size or dimension.

1.3. Assemblability

Assemblability or fitting quality is the capability of the components to fit together without deviation. Assemblability analysis is essential at the design stage, particularly when the assembly is not enforced through the use of fasteners. In mechanical assemblies that are supported by fasteners, kinematic variations are constrained and geometric tolerance will not affect the assemblability unless it produces inadvertent interference. The problem of assemblability analysis is closely connected with the tolerance analysis of the mechanical assemblies. In the design stage of a mechanical assembly, the designer often specifies the tolerance of the main design feature as the functional tolerance. From the top-down design perspective, the designer may not have details about available manufacturing processes, so it is important for designers to know at least that the nominal components will fit together. It is also notable for designers to recognize which dimensions will affect the assemblabilty. This is assemblabilty analysis with nominal dimensions. By assuming each dimension and tolerance in every component to be at its maximum or minimum limit, the assembly is tested to check whether there is any interference between components. The purpose of this configuration is to allocate appropriate specification of tolerances on parts or components, optimized configuration guidelines which are often based on manufacturing cost considerations. This assemblabilty analysis, as expressed by Zou and Morse [2] may be used when the designer wants to guarantee that the components can be assembled.

2. FUZZY ANALYSIS

Fuzzy logic is well suited for representation of vagueness considering its mathematical and logical base. According to Dupinet et al. [3] fuzzy logic is based on the concept of representing knowledge linguistically rather than mathematically. Transition from one category – concept, idea, or problem state – to the next is gradual with some states having greater or less membership in the one set and then another. Most design problems are deceptively complex. Neural networks can predict individual part tolerances, according to Ji et al. [4]. This is the primary reason that the current breed of expert systems has failed to grow rapidly in the design community. Fuzzy logic approach to control problems mimics how a person would make decisions, only much faster when coded as computational logic. Fuzzy rules have been advocated as a key tool for expressing pieces of knowledge in “fuzzy logic”. The tolerances are analyzed by comparing their geometrical features to the manufacturing capabilities of a workshop. Fuzzy analysis is performed comparing the geometric tolerances to the available workshop capabilities. The fuzzy linguistic variable is named compatibility that is subdivided in the following categories: best fitting quality, better fitting quality, good fitting quality, priority based acceptable fitting, and maximum clearance fitting quality [5–8].

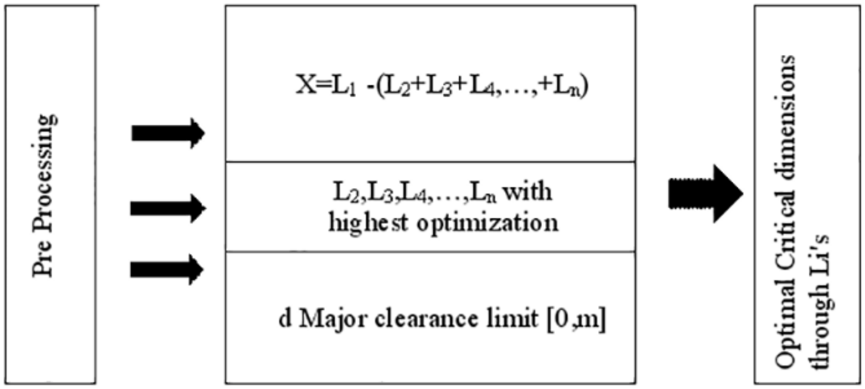

Fig. 1. Program Dependence Graph (PDG).

Table 2. Binary table.

Row. No	L1	L2	L3	L4
1	0	0	0	0
2	0	0	0	1
3	0	0	1	0
4	0	0	1	1
5	0	1	0	0
6	0	1	0	1
7	0	1	1	0
8	0	1	1	1
9	1	0	0	0
10	1	0	0	1
11	1	0	1	0
12	1	0	1	1
13	1	1	0	0
14	1	1	0	1
15	1	1	1	0
16	1	1	1	1

3. PREPROCESS

Step 1. Fixing level for $L1, L2, L3, L4$, Ln values in [0, 1] condition namely binary range allotment method.

Step 2. Rotate the values of d as per requirement of customer's view or requirements.

4. PROGRAM DEPENDENCE GRAPH (PDG)

A program dependence graph is a suitable internal program representation of monolithic programs for to carry out certain engineering operations such as scheming and computation of program metrics.

5. PROPOSED ALGORITHM

Step 1: Assign $d = 0$

Step 2: Input the values (L1, L2, L3, L4, and Ln, m)

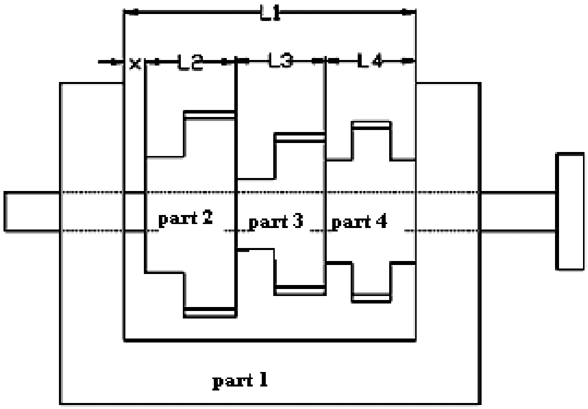

Fig. 2. Gear box assembly.

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Step 3: Assign X=L1-(L2 + L3 + L4, Ln)

Step 4: If $X < 0$ Print Interference Fit
            Else
                If X=0 Print Transition Fit
                    Else
                    If X$\leq$d Print L1, L2, L3, L4, Ln & X
                    End If;
                End If;
            d=d+i
            If d$\leq$m then go to step 2
            End If;
                End If;
```

6. REAL TIME APPLICATION AND EXPERIMENTAL RESULT

In some assemblies, assemblability analysis may be less important because assembly is guaranteed through the use of fasteners such as screws, adhesives, springs, etc. These assemblies permit dimensional variations so geometric tolerances will not affect assemblability. However, the functionality or the quality of such assemblies will be affected by how well the components assemble. In many cases, clearances can become the design criteria by which quality is evaluated, according to Dong and Soom [9]. These clearances are limited to maximum and minimum values.

To demonstrate an example of the proposed models a gear box assembly will be used. The set up is shown below in Fig. 2. The explicit design function can be expressed by a parametric relationship. Tolerance allocation specifies the final tolerance of the assembly. It makes it possible for the designer to meet the clearance requirements therein, while reducing manufacturing costs and improving efficiency through quality of fit. Tolerance allocation stimulates the designer and manufacturer to improve the overall production process. The dimensions of the simple linear gear box assembly, shown in Fig. 2, are given in Table 3. All dimensions are in mm.

Chase and Greenwood [1] proposed upper and lower limits. The data taken in our case is tabulated in Table 3.

Table 3. Specification of gear box assembly.

Specification	Nominal in mm	Upper limit	Lower limit
L_1	190	0.962	0.3048
L_2	74	0.7096	0.1524
L_3	78	0.7096	0.1524
L_4	36	0.3810	0.122

X = L1 - (L2 + L3 + L4)
X = 190 - (74 + 78 + 36) = 2
Major Clearance Constraint = d = 2 (in fuzzy space)
Also discussed in the following manner
(i) Xmax = Max [L1] - (Min [L2] + Min [L3] + Min [L4]) [Refer in Table 2 row no. 9]
(ii) Xmin = Min [L1]- (Max [L2] + Max [L3] + Max [L4]) [Refer in Table 2 row no. 8]

Table 4. Final tolerance design by proposed method for gear box assembly.

Specification	Nominal in mm	Upper limit	Lower limit
L_1	190	0.9	0.6
L_2	74	0.5	0.1
L_3	78	0.5	0.1
L_4	36	0.2	0.1

7. RESULTS AND DISCUSSION

In mechanical design, geometric and dimensional tolerances are used to specify the range within which a part geometry and size may vary while conforming to the functional requirements. Assigned tolerances have a direct effect not only on the machining cost but also on the product quality. Unnecessarily tight tolerances result in high production cost, yet the tolerances should ensure that the functional performance requirements of the products stay within a satisfactory range. Tolerances which are too loose can affect the product quality, increase the scrap rate and production cost.

The authors have here analysed six levels of suitability in the design of tolerance as follows:

1. When the major dimension of part 1 (L1) is greater than subassembly dimension of part 2 (L2), Part 3 (L3) and Part 4 (L4); and it is also equal to the addition of these three (L2, L3 and L4), the level of suitability is the best fitness with minimum cost (for example, row 2 in Appendix 1).
2. While the major dimension of part 1 (L1) is greater than subassembly dimension of part 2 (L2), part 3 (L3) and part 4 (L4); and it is also an unequal to the addition of those three (L2, L3 and L4), the level of suitability is the better fitness with minimum cost (for example, rows 12, 14 and 15 in Appendix 2).
3. If the major dimension of part 1 (L1) is not only greater than subassembly dimension of part 2 (L2), part 3 (L3) and part 4 (L4) also stands for the suitability of good fitness with minimum cost (for example, rows 12, 14 and 15 in Appendix 3).
4. The major dimension of part 1 (L1) is greater than the subassembly dimension of part 2 (L2), part 3 (L3) and part 4 (L4); and not equal to the addition of L2,L3 and L4.This level provides acceptable clearance priority based on cost satisfaction (for example, rows 10, 11 and 13 in Appendix 4).
5. The single argumentation that the major dimension of part 1 (L1) is greater than the subassembly dimension of part 2 (L2), part 3 (L3) and part 4 (L4); and there is no other hand of the addition. This

formula stands for the level of suitability is maximum clearance fitness with high cost (for example, row 2, no. 9 in Appendix 5).

6. Appendix 6, Table 2 row number 9 predicts maximum clearance with most expensive at the level of suitability. Also Table 4 explains the best fit with minimum cost for gear box assembly.

Finally, Appendix 7 shows fuzzy fitness with respect to the critical dimension chart.

8. CONCLUSION

The proposed algorithm gives basic feasible solution for tolerance allocation (clearance in %) in mechanical assemblies. Traditional approaches do not achieve the high level of accuracy provided by the one proposed. The proposed algorithm categorizes the tolerance fit into six different levels along with optimum cost.

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APPENDIX 1: BEST FIT WITH MINIMUM COST

Sl. No	L1	L2	L3	L4	X
1	0.6	0.1	0.4	0.1	1.11022E-16
2	0.6	0.2	0.3	0.1	1.11022E-16
3	0.6	0.3	0.2	0.1	1.11022E-16
4	0.6	0.4	0.1	0.1	1.11022E-16
5	0.7	0.1	0.4	0.2	1.11022E-16
6	0.7	0.1	0.5	0.1	1.11022E-16
7	0.7	0.2	0.3	0.2	1.11022E-16
8	0.7	0.3	0.2	0.2	1.11022E-16
9	0.7	0.4	0.1	0.2	1.11022E-16
10	0.7	0.5	0.1	0.1	1.11022E-16
11	0.8	0.2	0.5	0.1	1.11022E-16
12	0.8	0.5	0.2	0.1	1.11022E-16
13	0.9	0.2	0.5	0.2	1.11022E-16
14	0.9	0.5	0.2	0.2	1.11E-16

APPENDIX 2: BETTER FIT

Sl. No	L1	L2	L3	L4	X
1	0.5	0.1	0.1	0.1	0.2
2	0.6	0.1	0.1	0.2	0.2
3	0.6	0.1	0.2	0.1	0.2
4	0.6	0.2	0.1	0.1	0.2
5	0.7	0.1	0.1	0.3	0.2
6	0.7	0.1	0.2	0.2	0.2
7	0.7	0.1	0.3	0.1	0.2
8	0.7	0.2	0.1	0.2	0.2
9	0.7	0.2	0.2	0.1	0.2
10	0.7	0.3	0.1	0.1	0.2
11	0.8	0.1	0.1	0.4	0.2
12	0.8	0.1	0.2	0.3	0.2
13	0.8	0.1	0.3	0.2	0.2
14	0.8	0.1	0.4	0.1	0.2
15	0.8	0.2	0.1	0.3	0.2
16	0.8	0.2	0.2	0.2	0.2
17	0.8	0.2	0.3	0.1	0.2
18	0.8	0.3	0.1	0.2	0.2
19	0.8	0.3	0.2	0.1	0.2
20	0.8	0.4	0.1	0.1	0.2
21	0.9	0.1	0.1	0.5	0.2
22	0.9	0.1	0.2	0.4	0.2
23	0.9	0.1	0.3	0.3	0.2
24	0.9	0.1	0.4	0.2	0.2
25	0.9	0.1	0.5	0.1	0.2
26	0.9	0.2	0.1	0.4	0.2
27	0.9	0.2	0.2	0.3	0.2
28	0.9	0.2	0.3	0.2	0.2
29	0.9	0.2	0.4	0.1	0.2
30	0.9	0.3	0.1	0.3	0.2
31	0.9	0.3	0.2	0.2	0.2
32	0.9	0.3	0.3	0.1	0.2
33	0.9	0.4	0.1	0.2	0.2
34	0.9	0.4	0.2	0.1	0.2
35	0.9	0.5	0.1	0.1	0.2
36	1	0.1	0.1	0.6	0.2
37	1	0.1	0.2	0.5	0.2
38	1	0.1	0.3	0.4	0.2
39	1	0.1	0.4	0.3	0.2
40	1	0.1	0.5	0.2	0.2
41	1	0.1	0.6	0.1	0.2
42	1	0.2	0.1	0.5	0.2
43	1	0.2	0.2	0.4	0.2
44	1	0.2	0.3	0.3	0.2
45	1	0.2	0.4	0.2	0.2
46	1	0.2	0.5	0.1	0.2
47	1	0.3	0.1	0.4	0.2
48	1	0.3	0.2	0.3	0.2
49	1	0.3	0.3	0.2	0.2
50	1	0.3	0.4	0.1	0.2
51	1	0.4	0.1	0.3	0.2
52	1	0.4	0.2	0.2	0.2
53	1	0.4	0.3	0.1	0.2
54	1	0.5	0.1	0.2	0.2
55	1	0.5	0.2	0.1	0.2
56	1	0.6	0.1	0.1	0.2
57	0.4	0.1	0.1	0.1	0.1
58	0.5	0.1	0.1	0.2	0.1
59	0.5	0.1	0.2	0.1	0.1
60	0.5	0.2	0.1	0.1	0.1
61	0.6	0.1	0.1	0.3	0.1
62	0.6	0.1	0.2	0.2	0.1
63	0.6	0.1	0.3	0.1	0.1
64	0.6	0.2	0.1	0.2	0.1
65	0.6	0.2	0.2	0.1	0.1
66	0.6	0.3	0.1	0.1	0.1
67	0.7	0.1	0.1	0.4	0.1
68	0.7	0.1	0.2	0.3	0.1
69	0.7	0.1	0.3	0.2	0.1
70	0.7	0.1	0.4	0.1	0.1
71	0.7	0.2	0.1	0.3	0.1
72	0.7	0.2	0.2	0.2	0.1
73	0.7	0.2	0.3	0.1	0.1
74	0.7	0.3	0.1	0.2	0.1
75	0.7	0.3	0.2	0.1	0.1
76	0.7	0.4	0.1	0.1	0.1
77	0.8	0.1	0.1	0.5	0.1
78	0.8	0.1	0.2	0.4	0.1
79	0.8	0.1	0.3	0.3	0.1
80	0.8	0.1	0.4	0.2	0.1
81	0.8	0.1	0.5	0.1	0.1
82	0.8	0.2	0.3	0.2	0.1
83	0.8	0.2	0.4	0.1	0.1
84	0.8	0.3	0.1	0.3	0.1
85	0.8	0.3	0.2	0.2	0.1
86	0.8	0.3	0.3	0.1	0.1
87	0.8	0.4	0.1	0.2	0.1
88	0.8	0.4	0.2	0.1	0.1
89	0.8	0.5	0.1	0.1	0.1
90	0.9	0.1	0.1	0.6	0.1
91	0.9	0.1	0.2	0.5	0.1
92	0.9	0.1	0.5	0.2	0.1
93	0.9	0.1	0.6	0.1	0.1
94	0.9	0.2	0.1	0.5	0.1
95	0.9	0.2	0.2	0.4	0.1
96	0.9	0.2	0.3	0.3	0.1
97	0.9	0.2	0.4	0.2	0.1
98	0.9	0.2	0.5	0.1	0.1
99	0.9	0.3	0.1	0.4	0.1
100	0.9	0.3	0.2	0.3	0.1
101	0.9	0.3	0.3	0.2	0.1
102	0.9	0.3	0.4	0.1	0.1
103	0.9	0.4	0.1	0.3	0.1
104	0.9	0.4	0.2	0.2	0.1
105	0.9	0.4	0.3	0.1	0.1
106	0.9	0.5	0.1	0.2	0.1
107	0.9	0.5	0.2	0.1	0.1
108	0.9	0.6	0.1	0.1	0.1
109	1	0.1	0.1	0.7	0.1
110	1	0.1	0.2	0.6	0.1
111	1	0.1	0.3	0.5	0.1
112	1	0.1	0.6	0.2	0.1
113	1	0.1	0.7	0.1	0.1
114	1	0.2	0.1	0.6	0.1
115	1	0.2	0.2	0.5	0.1
116	1	0.2	0.4	0.3	0.1
117	1	0.2	0.5	0.2	0.1
118	1	0.2	0.6	0.1	0.1
119	1	0.3	0.1	0.5	0.1
120	1	0.3	0.4	0.2	0.1
121	1	0.3	0.5	0.1	0.1
122	1	0.4	0.1	0.4	0.1
123	1	0.4	0.2	0.3	0.1
124	1	0.4	0.3	0.2	0.1
125	1	0.4	0.4	0.1	0.1
126	1	0.5	0.1	0.3	0.1
127	1	0.5	0.2	0.2	0.1
128	1	0.5	0.3	0.1	0.1
129	1	0.6	0.1	0.2	0.1
130	1	0.6	0.2	0.1	0.1
131	1	0.7	0.1	0.1	0.1

APPENDIX 3: GOOD FIT

Sl. No	L1	L2	L3	L4	X
1	0.6	0.1	0.1	0.1	0.3
2	0.7	0.1	0.1	0.2	0.3
3	0.7	0.1	0.2	0.1	0.3
4	0.7	0.2	0.1	0.1	0.3
5	0.8	0.1	0.1	0.3	0.3
6	0.8	0.1	0.2	0.2	0.3
7	0.8	0.1	0.3	0.1	0.3
8	0.8	0.2	0.1	0.2	0.3
9	0.8	0.2	0.2	0.1	0.3
10	0.8	0.3	0.1	0.1	0.3
11	0.9	0.1	0.1	0.4	0.3
12	0.9	0.1	0.2	0.3	0.3
13	0.9	0.1	0.3	0.2	0.3
14	0.9	0.1	0.4	0.1	0.3
15	0.9	0.2	0.1	0.3	0.3
16	0.9	0.2	0.2	0.2	0.3
17	0.9	0.2	0.3	0.1	0.3
18	0.9	0.3	0.1	0.2	0.3
19	0.9	0.3	0.2	0.1	0.3
20	0.9	0.4	0.1	0.1	0.3
21	1	0.1	0.1	0.5	0.3
22	1	0.1	0.2	0.4	0.3
23	1	0.1	0.3	0.3	0.3
24	1	0.1	0.4	0.2	0.3
25	1	0.1	0.5	0.1	0.3
26	1	0.2	0.1	0.4	0.3
27	1	0.2	0.2	0.3	0.3
28	1	0.2	0.3	0.2	0.3
29	1	0.2	0.4	0.1	0.3
30	1	0.3	0.1	0.3	0.3
31	1	0.3	0.2	0.2	0.3
32	1	0.3	0.3	0.1	0.3
33	1	0.4	0.1	0.2	0.3
34	1	0.4	0.2	0.1	0.3
35	1	0.5	0.1	0.1	0.3

APPENDIX 4: ACCEPTABLE CLEARANCE WITH PRIORITY BASED ON COST

Sl. No	L1	L2	L3	L4	X
1	0.7	0.1	0.1	0.1	0.4
2	0.8	0.1	0.1	0.2	0.4
3	0.8	0.1	0.2	0.1	0.4
4	0.8	0.2	0.1	0.1	0.4
5	0.9	0.1	0.1	0.3	0.4
6	0.9	0.1	0.2	0.2	0.4
7	0.9	0.1	0.3	0.1	0.4
8	0.9	0.2	0.1	0.2	0.4
9	0.9	0.2	0.2	0.1	0.4
10	0.9	0.3	0.1	0.1	0.4
11	1	0.1	0.1	0.4	0.4
12	1	0.1	0.2	0.3	0.4
13	1	0.1	0.3	0.2	0.4
14	1	0.1	0.4	0.1	0.4
15	1	0.2	0.1	0.3	0.4
16	1	0.2	0.2	0.2	0.4
17	1	0.2	0.3	0.1	0.4
18	1	0.3	0.1	0.2	0.4
19	1	0.3	0.2	0.1	0.4
20	1	0.4	0.1	0.1	0.4

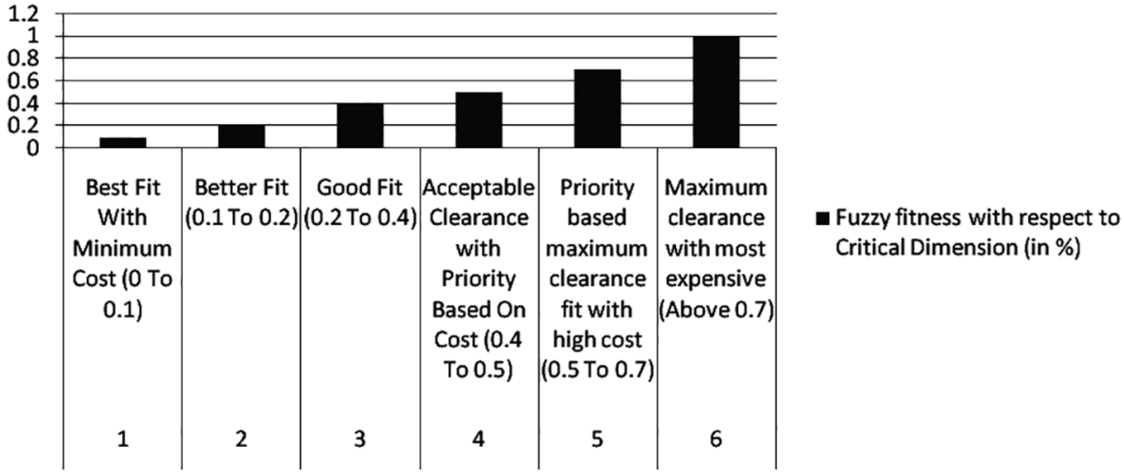
APPENDIX 5: PRIORITY BASED MAXIMUM CLEARANCE FIT WITH HIGH COST

Sl.No	L1	L2	L3	L4	X
1	0.9	0.1	0.1	0.1	0.6
2	1	0.1	0.1	0.2	0.6
3	1	0.1	0.2	0.1	0.6
4	1	0.2	0.1	0.1	0.6
5	0.8	0.1	0.1	0.1	0.5
6	0.9	0.1	0.1	0.2	0.5
7	0.9	0.1	0.2	0.1	0.5
8	0.9	0.2	0.1	0.1	0.5
9	1	0.1	0.1	0.3	0.5
10	1	0.1	0.2	0.2	0.5
11	1	0.1	0.3	0.1	0.5
12	1	0.2	0.1	0.2	0.5
13	1	0.2	0.2	0.1	0.5
14	1	0.3	0.1	0.1	0.5

APPENDIX 6: MAXIMUM CLEARANCE WITH MOST EXPENSIVE

Sl.No	L1	L2	L3	L4	X
1	1	0.1	0.1	0.1	0.7

APPENDIX 7: FUZZY FITNESS WITH RESPECT TO CRITICAL DIMENSION (IN %)



REFERENCES

1. Chase, K.W. and Greenwood, W.H., "Design issues in mechanical tolerance analysis", *Machining Review*, Vol 1, No. 1, pp. 50–59, 1990.
2. Zou, Z. and Morse, E.P., "Applications of the gap space model for multidimensional mechanical assemblies", *Transactions of the ASME Journal of Computing and Information Science and Engineering*, Vol. 3, pp. 22–30, 2003.
3. Dupinet, E., Balazinski, M. and Caogala, E., "Tolerance allocation based on fuzzy logic and simulated annealing", *Journal of Intelligent Manufacturing*, Vol. 7, pp. 487–497, 1996.
4. Ji, S., Li, X., Ma, Y. and Cai, H., "Optimal tolerance allocation based on fuzzy comprehensive evaluation and genetic algorithm", *International Journal of Advanced Manufacturing and Technology*, Vol. 16, pp. 461–468, 2000.
5. Kopardekar, P. and Anand, S., "Tolerance allocation using neural networks", *International Journal of Advanced Machining Technology*, Vol. 10, pp. 269–276, 1995.
6. Spotts, M.F., "Allocation of tolerance to minimize costs of assembly", *ASME Journal of Engineering for Industry*, Vol. 95, pp. 762–764, August 1973.
7. Maran, M., Manikanndan, G., and Thiagarajan, K., "Fuzzy expert system for overall equipment effectivess", *European Journal of Scientific Research*, Vol. 83, No. 3, 2012.
8. Sudhakar, P., Poonkuzhali, G., Thiagarajan. K, and Sarukesi, K., "Terminator for e-mail spam-a fuzzy approach revealed", *International Journal of Computers*, Vol. 5, No. 3, 2011.
9. Dong, Z. and Soom, A., "Automatic optimal tolerance design for related dimension chains", *ASME Machining Review*, Vol. 3, No. 4, pp. 262–271, December 1990.