Optimum Group Size Selection for Launch Vehicle Sections Linear Assembly by Selective Assembly Method

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Abstract- **Selective assembly is an accepted cost effective approach for reducing the overall variation and thus producing high precision assembly from the relatively low precision components. In selective assembly parts are mass produced to specific tolerance and allowance in an economic manner then sorted out into various grades according to size. Parts are then selectively assembled. In this paper selective assembly method is used to find the optimum group size for relatively small batch quantity Launch vehicle sections with wider tolerances to match with launcher mating feature. Numerous analyses were made with group size six. Maintaining inventory for group size more than three for small batch quantity is very difficult and involves huge investment. Moreover there is a chance of few sections of particular group may become surplus due to non-utilisation. This selective assembly method proposes a best group size and its combination for very small batch size quantity with wider tolerance. MATLAB Genetic Algorithm (GA) tool is used for analysing the best combination. The mating sections from corresponding selective groups are assembled so that smaller clearances can be obtained which are better than those achieved in the interchangeable level at lower total cost. This method is very much effective where the process variability of assembly is too large in spite of precisely machined components.**

Keywords - Selective assembly, Launch vehicle, Launcher, Genetic algorithm.

I. INTRODUCTION

Tolerance design has evolved over years and has reached their current state through an ever increasing quest for efficiency in producing products that satisfy customer requirements. Every products manufactured are toleranced. Manufacturing process used to make product controlled by some form of specification limit. Tolerance design is a balancing process. It is designed to balance product or process functional quality with overall cost. Quality means excellence in every aspect of the product or service of an organization. The organization must produce/serve a quality product/service to satisfy the customer's tangible/intangible requirements. In manufacturing, variation can be identified as the difference between the targeted specification and the actual dimension manufactured. Since, it is impossible to manufacture the products with exact target specifications, allowable variations are commonly employed to the specifications. Manufacturing with tighter specification may improve the functional performance of the product, but it will increase the total cost. It is sometimes found that it is not economic to manufacture sections to the required high degree of accuracy for their correct functioning. Instead, they are made in an economic manner, measured to the required high accuracy and graded or sorted into groups each of which contains such parts of the same size to within close limits Bonch and Osmolovskii [1], Koganov [2], Shemarin [3]. They are then assembled with mating parts which have been similarly graded. Ngoi and Min [4] presents a direct method to determine the working dimensions and tolerances of components that allows control of the assembly interaction concurrently. Since these interaction between components in an assembly plays a major role in the performance and reliability of the assembly. Siva kumar *et al* [5] developed a graphical representation which can help the process engineer to visualize the minimum & maximum values for assembly tolerances. This helps to determine the exact total manufacturing cost of the assembly to fix the tolerance which would not fall outside the limits prescribed. Chiu chi Nei [6] presents a novel formulation capable of designing process tolerances to minimize the expected loss of the entire process due to nonconforming parts by using exponential cost tolerance function to estimate the manufacturing cost and the standard normal probability curve to predict the scrap rate of the operation. Kannan and Jayabalan [7] proposed method of grouping for selective assembly can be effectively implemented for complex assemblies with number of groups to be portioned for selective assembly is less compared with Traditional Methods and in addition, the surplus parts are minimized. Shiv Kumar et al [8] Introduced new algorithm to reduce surplus parts almost to zero by Selective Assembly and it is achieved in two stages by using Genetic Algorithm. Kannan *et al* [9] proposed new Selective Assembly that is instead of assembling components from corresponding selective groups components from different combination can be assembled to achieve minimum clearance variation by using Genetic Algorithm to design the optimum tolerances of the individual components to achieve the required assembly tolerances, zero percentage rejection of the components and minimum cost manufacturing. Forouraghi [10] introduces a new method based on Genetic Algorithm(GA), which addresses both the worst case tolerance analysis of mechanical assemblies and robust design with a overall formulation based on manufacturing capability indices allow the GA to rank candidate design based on varying the tolerances around the nominal design parameter values.

The requirement of selective assembly has a wider scope in many engineering applications. Some of them are (i) Actuator rod bearings assembly for Control Fins (ii) assembly. The dimensional variation (tolerance variation) is parallel to the axis of the assembly in linear assembly as in the case of sections assembled in a launch vehicle. In radial assembly, the dimensional variation under consideration is radial like in shaft and hole (stud and hole) assembly. The tolerance variation is called as clearance variation or interference in radial assemblies. When the number of sections in an assembly is more than two and if the clearance variation is dependent on the quality characteristics contributed by the sections, then it is called a complex assembly. It can be linear (shell-shell assembly), or radial (stud corresponding hole clearance between stud and hole) or both (fully assembled launch vehicle).

Piston, piston ring and cylinder assembly for hydraulic actuators and (iii) Ball bearing assembly for electro mechanical actuator etc. The assembly products used in the selective assembly method can be classified into two groups: linear assembly and radial

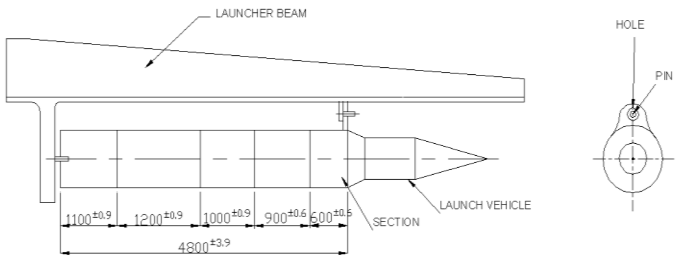

Figure:2. Launcher and Launch Vehicle in Mated Position

II. PROBLEM BACK GROUND

Launch Vehicles are rockets & launch vehicles used for launching satellites, warheads in a predetermined trajectory to achieve the expected performance of positioning the satellite in the orbit and hit the target respectively. These rockets, launch vehicles are divided into number of stages for easy separation of spend stages, separation of satellites for deployment in the orbit and separation of warheads for re-entry. All stages are further divided into number of sections or shells to enable installation of various on board systems such as propulsions, electrical & electronic packages, mechanical systems, hydraulic and pneumatic systems. Propulsion sections are normally fabricated by joining preciously rolled steel sheet metals with machined end rings by welding using welding fixtures. Other sections are fabricated by joining aluminium alloy rolled sheets orfibre reinforced plastic shells with end rings by riveting using riveting fixtures. Deviations are inevitable in any fabrication. In shell fabrication deviations are mainly due to various process variability such as machining, rolling welding & riveting (Figure-1). Due to various constrains /limitation these sections are fabricated, equipped with above mentioned on board systems at different places and moved for final assembly at launch sites. Fully integrated Launch vehicles are mated / engaged with holding & support mechanism available on launchers / launch tubes. These holding & support mechanisms are used for holding the Launch vehicle during transportation, erection, release the launch vehicle during lift off and retract back quickly to avoid collision with moving vehicle. Tolerance and adjustability of longitudinal dimension on these holding mechanisms are limited for reliable smooth engagement of launch vehicle with launcher (Figure-2). Any further adjustment on these mechanisms for accommodating increased or decreased length of launch vehicle, calls for elaborate time consuming load testing for proving the mechanisms at the new location. This adjustment is not possible particularly in the case of launch vehicle launcher due to less reaction time available to launch and also the launch vehicle has to be engaged at the time of need from the storage without any adjustment on launcher for safety and security reason. This necessitates the assembly of better combination of sections to produce Launch vehicle with minimum assembly variation in linear dimension, keeping the option of utilisation of all available sections.

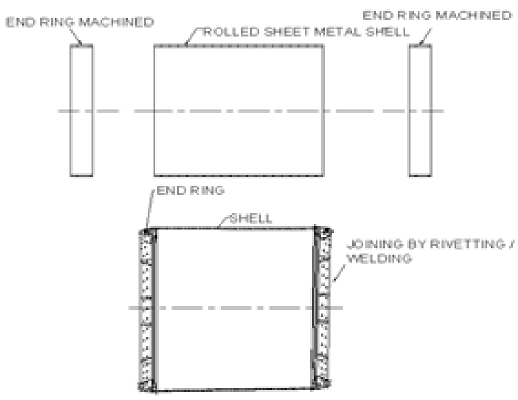

Figure 1. Rivetted Shell

III. PROBLEM

Variation is inevitable in any fabrication/manufacturing process. The variation here is difference between the linear dimension of the Launcher mating feature and the Launch vehicle feature (figure 3). This clearance is an important factor and it decides the quality of the assembly between the Launch vehicle and Launcher/Launch tube. Another important factor is unlike assembly , here mating parts (Launch vehicles) are expected to be replaced with another one during its service. Fabrication of these long length, large diameter ,different materials, various process , slender optimum thickness to have high strength to weight ratio are not an exemptions because some misalignments, deviations always occur in realising the sections. As the number of section joints increases the overall deviation in longitudinal location of holding features on launcher also increases/decreases (Figure4). Unlike mass produced components Launch vehicle section are produced in small batches due to high cost in realisation . Moreover the lead time in realising the component especially fibre reinforced plastic shells are extremely very high. Launch vehicle industries cannot afford to reject sections fabricated with wide tolerance.

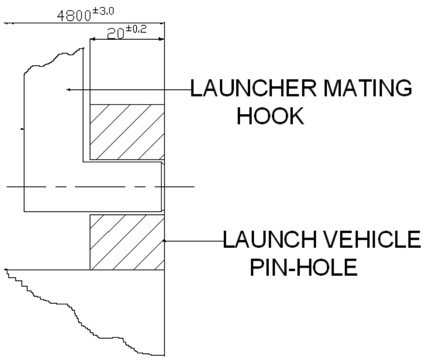

Figure:3. Mating Feature of Launch Vehicle & Launcher.

Sections with wide tolerance can be used to produce Launch vehicle to meet the mission requirement by selective assembly method. In this paper selective assembly method is used to find the optimum group size for Launch vehicle sections linear assembly considering small batch quantity. MATLAB Genetic Algorithm (GA) tool is used for finding the best combination of group size to minimize linear assembly variation.

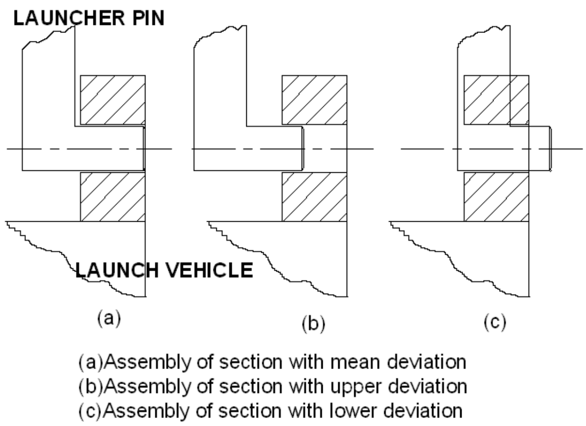

Figure:4. Relative Position of Launch Vehicle Pin-hole with respect to Launcher Pin

IV. LINEAR ASSEMBLY ANALYSIS

In linear assembly five numbers of sections with varying length is considered for analysis. The following assumption are made viz parallelism between end rings has been taken into consideration in the section linear dimension, concentricity of section end rings are within the specified value and its contribution in variation of linear dimension deviation is negligibly small. Fore-end and aft-end of sections as well as its orientation can not be changed as internal features in the sections are provided for specific subsystems. More over length of the sections are specific to meet the shape and size of subsystems, hence relative position of the sections in the assembly can not be changed. Sections in the assembly will have the different dimensional distribution and are manufactured by the same process. Sections are assembled horizontally on the assembly jig. The linear assembly of five sections A, B, C, D and E are considered for the analysis with the section length tolerance of Δ_A, Δ_B , Δ_C, Δ_D and Δ_E respectively (Figure5).

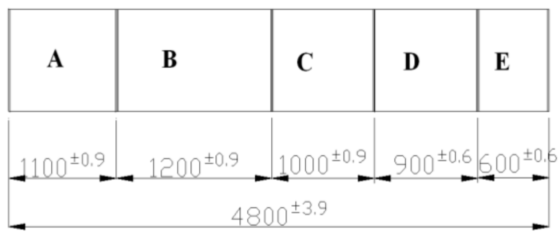

Figure.5. Linear Assembly

The selective assembly method with 'n' numbers of selective groups is considered for the analysis. The dimensional distributions of the sections are divided into 'n' groups .The group tolerance (δ_x) is $\frac{\Delta x}{n}$, where 'x' describes the corresponding mating sections of A, B, C, D and E. The upper deviation (T_{UD}) in an assembly is the sum of the maximum deviation of individual sections .The lower deviation (T_{LD}) in an assembly is the sum of the minimum deviation of individual sections ($\Delta_{x\ (min)}$). The upper and lower deviation tolerances of an assembly are,

b - Number of sections = 5

For each 'n' number of selective group combination, 'n' number of assemblies (population) can be produced. Each assembly will have different assembly deviation that lead assembly variations. The deviation range (T_{range}) for the assemblies of a combination is the subtraction of the minimum of T_{LD} from the maximum of T_{UD}.

$$T_{range} = \max(T_{UD}) - \min(T_{LD}) \quad (3)$$

In traditional selective assembly, the mating sections from the corresponding selective groups are assembled. The calculation of assembly variation in the conventional process is shown in Table 1. For example the first assembly set 1_A, 1_B, 1C, 1_D and 1_E first column in the combination of the sections A, B, C, D and E are carried from the first selective group. The upper limit for sections A, B, C is 3 and D, E is 2. And the lower limit is 0 for all A, B, C, D and E section .The upper deviation (T_{UD}) of an assembly from first set is 3+3+3+2+2 = 13 unit. Similarly T_{LD} is 0 units.

In Table 1, by selecting the best combination of sections with optimum group size, assembly variation can be reduced to a greater extent. For a combination of

selective groups, in one assembly set, upper deviation(T_{UD}) is the sum of the maximum deviations of the section's group deviations. So T_{UD} can be obtained by the sum of multiplications of group number (n_x) and group deviation (δ_x). Similarly the lower deviation (T_{LD}) is the sum of the minimum limits of the component's group deviations. It can be obtained by the sum of multiplications of (n_x–1) and δ_x. The maximum and minimum assembly deviation for a combination are,

$$T_{UD} = (n_A\times\delta_A)+(n_B\times\delta_B)+(n_C\times\delta_C)+(n_d\times\delta_d)+(n_e\times\delta_e) \quad (4)$$

$$T_{LD} = ((n_A-1)\delta_A) + ((n_B-1)\delta_B) + ((n_C-1)\delta_C) \quad (5)$$

TABLE 1
Conventional selective assembly procedure

$$T_{UD} = \Delta_{A(max)} + \Delta_{B(max)} + \Delta_{C(max)} + \Delta_{D(max)} + \Delta_{E(max)} \quad (1)$$

$$T_{LD} = \Delta_{A(min)} + \Delta_{B(min)} + \Delta_{C(min)} + \Delta_{D(min)} + \Delta_{E(min)} \quad (2)$$

Section (x)		Combination					
A		1_A	2_A	3_A	4_A	5_A	6_A
B		1_B	2_B	3_B	4_B	5_B	6_B
C		1_C	2_C	3_C	4_C	5_C	6_C
D		1_D	2_D	3_D	4_D	5_D	6_D
E		1_E	2_E	3_E	4_E	5_E	6_E
Assemy deviatin variaton (unit)	T_{UD}(unit)	13	26	39	52	65	78
	T_{LD} (unit)	0	13	26	39	52	65
Deviation range (T_{range})(unit))		78 – 0 = 78					

Table: 2 show an example for the combination of selective groups. The assembly deviation range for the assembly sets is calculated as follows. For example, the first assembly set of section 3A, 4_B, 5_C, 1_D and 2_E (first column in the combination) is considered. It means that the section A is from the third selective group, the section B is from the fourth selective group , the section C is from the fifth selective group, Section D is from first selective group and section E is the second selective group. The maximum assembly deviation is the sum of multiplications of selective groups and corresponding group deviations [(3 × 3 unit) + (4 × 3 unit)+(5 × 3 unit)+ (1 × 2 unit) + (2 × 2 unit) = 42 units]. Similarly, the minimum assembly deviation is the sum of multiplications of initial limits of the selective groups and their corresponding group deviations [(3–1)×3 unit) + (4–1) ×3 unit) + (5–1) × 3 unit)+(0 × 2)+ (1×2) = 29 units].

TABLE 2
Assembly variation calculation for linear assembly
(Random selective group)

Sections (x)	Combination					
A	3_A	6_A	2_A	1_A	5_A	4_A
B	4_B	3_B	5_B	2_B	6_B	1_B
C	5_C	1_C	6_C	4_C	3_C	2_C
D	1_D	5_D	4_D	6_D	2_D	3_D
E	2_E	4_E	3_E	5_E	1_E	6_E

Assembly deviation variation (unit)	T_{UD}(unit)	42	48	53	43	48	39
	T_{LD} (unit)	29	35	40	30	35	26
Deviation range (T_{range})(unit)		53 – 26 = 27					

The maximum and minimum deviation values for each assembly set of the combination are calculated. The assembly deviation variation for the first set is 42–29 = 13unit. In this combination of different selective groups, the assembly sets are obtained with equal and minimum assembly deviation (13 units). But each assembly sets are all scattered at different places

($4800^{+42UNIT}_{+29UNIT}$, $4800^{+48UNIT}_{+35UNIT}$, $4800^{+53UNIT}_{+40UNIT}$, $4800^{+43UNIT}_{+30UNIT}$ and $4800^{+39UNIT}_{+26UNIT}$) within the total assembly variation of $4800^{+53UNIT}_{+26UNIT}$. Therefore T_{range} (27 unit) for the entire sets (one combination) is the difference between the maximum value T_{max} (53 unit) and minimum value of T_{min} (26 unit). So, the best combination is to be selected such that it results in the minimum assembly deviation in each assembly sets as well as minimum assembly variation in the entire sets of the combination. This complex process of finding the best combination that yields minimum assembly variation can be carried through the optimization tools.

A. *Best selective group combination using GA*

GA is used to find the best combination of selective groups of mating sections for selective assembly to obtain the minimum assembly variation. The length of the chromosome for this problem depends on the number of group size(n) and mating sections (b) in an assembly. Each section assembly is considered as a substring. So, the chromosome consists of ‘n’ numbers of substrings, and individual substrings are divided into ‘b’ number of genes. Totally there will be (n×b) numbers of genes in a chromosome. Figure.7 shows the structure of the chromosome for the linear assembly example with the sections A, B, C, D and E. There are six substrings. Each ubstring includes five genes that results 30 genes in a chromosome.

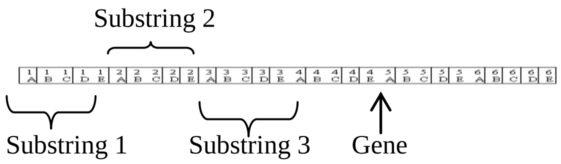

Figure.7 Chromosome structure for linear assembly

GA consists of six modules namely, input module, initialization module, evaluation module, new population generation module, termination module and output module. MATLAB GA tool is used to find the best combination of different group size. Cross over operation is carried out only between the corresponding substrings with selected cutting points. Cutting points are randomly generated.

The best chromosome in each iteration is stored. The best among the best stored is the optimal one. The best chromosome having a minimum range is given as the output. Large numbers of best combinations with same T_{range} were obtained. For the purpose of presentation only one such combination is given from each group. Selective group size six best combinations for the linear assembly is presented in Table 3. To obtain the possible minimum T_{range} for this small batch quantity airframe section group size 2,3,4,5,7,8,9 are also analysed. Best combination from these group size are shown in Tables 4, 5, 6, 7, 8, 9 and 10 respectively.

B. *Output module*

Table 3: Best combinations of linear assembly for selective group size ‘2’

Section (a)	Best combination		T_{range} (unit)
A	2	1	60 –18 = 42
B	1	2	
C	2	1	
D	1	2	
E	1	2	
T_{UD}(unit)	57	60	
T_{LD} (unit)	18	21	

Table 4: Best combinations of linear assembly for selective group size ‘3’

Section (a)	Best combination			T_{range} (unit)
A	1	3	2	52 – 26 =26
B	2	1	3	
C	3	2	1	
D	3	2	1	
E	1	2	3	
T_{UD}(unit)	52	52	52	
T_{LD} (unit)	26	26	26	

Table 5: Best combinations of linear assembly for selective group size ‘4’

Section (a)	Best combination				T_{range} (unit)
A	4	3	2	1	49.5 – 28.5 =21
B	1	2	3	4	
C	3	2	1	4	
D	1	4	3	2	
E	3	2	4	1	
T_{UD}(unit)	48	49.5	48	49.5	
T_{LD} (unit)	28.5	30	28.5	30	

Table 6: Best combinations of linear assembly for selective group size '5'

Section (a)	Best combination					T_{range} (unit)
A	4	1	2	5	3	46.8 – 31.2 =15.6
B	2	4	5	1	3	
C	3	4	2	5	1	
D	5	3	2	1	4	
E	1	3	4	2	5	
T_{UD}(unit)	46.8	46.8	46.8	46.8	46.8	
T_{LD} (unit)	31.2	31.2	31.2	31.2	31.2	

Table 7: Best combinations of linear assembly for selective group size '6'

Section (a)	Best combination						T_{range} (unit)
A	3	2	4	1	5	6	46 – 32 = 14
B	1	6	4	3	2	5	
C	5	3	6	4	2	1	
D	6	2	1	5	4	3	
E	3	4	1	6	5	2	
T_{UD}(unit)	45	45	46	46	45	46	
T_{LD} (unit)	32	32	33	33	32	33	

Table 8: Best combinations of linear assembly for selective group size '7'

Section (a)	Best combination							T_{range} (unit)
A	1	7	2	4	6	3	5	44.57 – 33.43 =11.14
B	5	3	6	1	7	4	2	
C	4	2	6	5	1	7	3	
D	7	1	2	6	3	4	5	
E	4	7	3	5	2	1	6	
T_{UD}(unit)	44.57	44.57	44.57	44.57	44.57	44.57	44.57	
T_{LD} (unit)	33.43	33.43	33.43	33.43	33.43	33.43	33.43	

Table 9: Best combinations of linear assembly for selective group size '8'

Section (a)	Best combination								T_{range} (unit)
A	2	8	6	3	4	1	7	5	44.25 – 33.75 =10.50
B	7	2	4	6	8	3	5	1	
C	7	2	3	4	5	8	1	6	
D	1	6	8	2	3	5	7	4	
E	4	5	2	8	1	6	3	7	
T_{UD}(unit)	43.50	43.50	44.25	44.25	44.25	43.50	44.25	43.50	
T_{LD} (unit)	33.75	33.75	34.50	34.50	34.50	33.75	34.50	33.75	

Table 10: Best combinations of linear assembly for selective group size '9'

Section (a)	Best combination									T_{range} (unit)
A	5	8	2	6	7	1	4	3	9	44-34 =10
B	8	3	9	5	6	7	1	4	2	
C	3	4	1	5	2	6	9	7	8	
D	4	6	8	1	7	5	9	2	3	
E	5	4	6	8	3	7	2	9	1	
T_{UD}(unit)	44.00	43.33	42.66	44.00	43.33	44.00	42.66	42.66	43.33	
T_{LD} (unit)	35.33	34.67	34.00	35.33	34.67	35.33	34.00	34.00	34.67	

5. Results: Minimum T_{range} best combination for five shell assembly

The minimum T_{range} best combination for different group size is presented in Table 11. From the table it is clear that the difference in percentage reduction of T_{range} is better for group size number 2,3,4,5.The percentage reduction is 46% for group size 2, 67% for group size 3, 73% for group size 4 and 80% for group size 5. For group size 6, 7, 8 and 9 though the T_{range} is less the percentage reduction is only marginal that is 87% which is only 7% increase from group size 5.To achieve this the small batch quantity size of ten to fifteen to be divided into maximum group size of 9 which is highly complex process, not economical will result in number of surplus parts. Considering all the above the better group size are only 2, 3, 4 and 5.In all these four group 2 and 4 the minimum T_{range} analysed by GA are 42, 21 where as the minimum possible T_{range} is 39 and 19.5 respectively. A better tool than GA can be used for finding combination for above. Group size 3,5 the T_{range} is 26 and 15.6 which is possible to achieve by GA. The reduction in T_{range} for group size 3 ,5 are 52 (78-26) units and 62.4 (78-15.60)units ,equal to 5200 μm and 6240 μm respectively. To achieve the further 13.37% reduction the small batch quantity needs to be divided into five groups. Considering airframe section availability at any particular point of time Group size 3 is the most preferred group size than 5.

FIGURE 9: COMPARISION OF BEST COMBINATION (MINIMUM Trange) FOR FIVE SHELLS

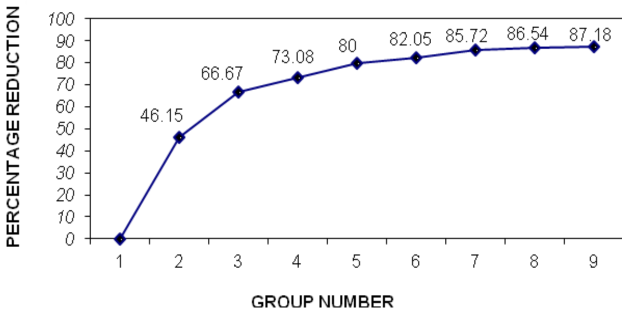

Table 11: Comparison of T_{range} for different selective group size

Selective Group size	T_{RANGE} (MINIMUM POSSIBLE)	T_{RANGE} (ACHIEVED BY G.A)	T_{RANGE} Difference with respect to Group size1	Percentage T_{RANGE} reduction with respect to Group size1	Percentage T_{RANGE} Difference Between Adjacent group
1	78.00	78.00	00.00	-	-
2	39.00*	42.00	36.00	46.15	46.15
3	26.00	26.00	52.00	66.67	20.52
4	19.50*	21.00	57.00	73.08	6.41
5	15.60	15.60	62.40	80.00	6.92
6	13.00*	14.00	64.00	82.05	2.05
7	11.14	11.14	66.86	85.72	3.67
8	9.75*	10.50	67.50	86.54	0.82

V. CONCLUSION

In conventional selective assembly, the mating sections from corresponding selective groups are assembled. In this conventional procedure, the assembly variations are more and the assembly tolerance has to be minimized considerably. The new method proposed in this chapter minimizes the assembly variation by selecting the sections from the different selective groups using the best combination. Genetic algorithm is successfully used for linear assemblies sections to obtain the best combinations of selective groups.

In this model, the sections considered are simple linear assembly. It can be applied to any kind of assemblies. The group size of two to nine is considered for the analysis. It can be extended to any number of groups with the same procedure. The new model will help in designing selective assembly to suit the specific requirements. In conventional selective assembly the mating sections from corresponding selective group are assembled. In this conventional procedure, the assembly variations are more and the assembly tolerance has to be minimised considerably. The new method proposed in this chapter minimizes the assembly variation by selective group among the best combination. Genetic algorithm is successfully used for linear assembly to obtain the best combination of selective group. The optimum suitable group give considerable reduction in T-range is 3.This mean that the small batch quantity of Launch vehicle sections can be conveniently divided into 3 groups and can be assembled with minimum assembly variation without any surplus sections left out. With this minimum assembly variation for particular configuration Launch vehicle can be mated with the Launcher with out any difficulty and with shortest possible reaction time for launch.

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