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Tolerance Stack-up Analysis -A review

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Abstract : Lowering of manufacturing cost with higher accuracy is always demanded in industry to increase profit. It is essential to check the tolerances after designing the component. Such kind of analysis is performed by two ways: Bottom to top analysis and top to bottom analysis. There are some methods available for bottom to top tolerance analysis. Tolerance stack up analysis is used to assign tolerance scientifically to the component. The role of Tolerance stack-up analysis becomes very crucial when it is to be applied for a very large assembly like aircraft wing. When proper Tolerance stack up analysis is not performed, it leads to many odd situations like generation of gap, rotation of parts etc. which may lead to rejection. This review paper is carried out to summarize suitable method for tolerance stack up analysis especially for large assemblies.

Keywords: Tolerance, Stack-up condition, Stack-up analysis, bottom to top approach

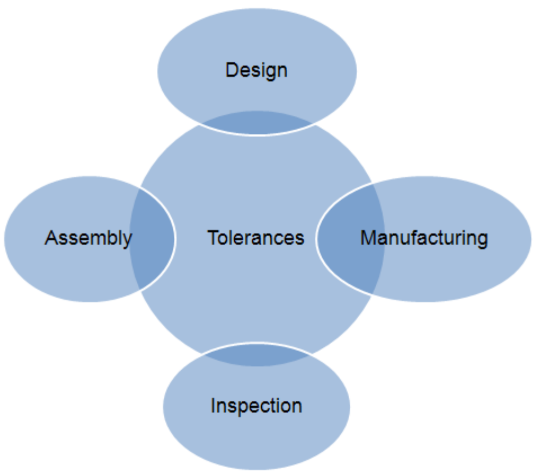
I. INTRODUCTION

Tolerance plays a vital role in any industrial product. Designer has to be very careful while dealing with tolerance. It is highly demanded to sell a product at low cost with higher accuracy. So it can perform efficiently. To fulfill such requirements it is advised to know about tolerance in deep.

1.1 Role of tolerance

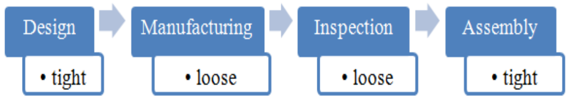
Manufacturing planner is focused on operation based tolerance allocation to minimize manufacturing cost.

Quality assurance verifies that the manufactured part comply with design specifications or not. So designer has to define drawings in such manner that both these requirements can be satisfied.



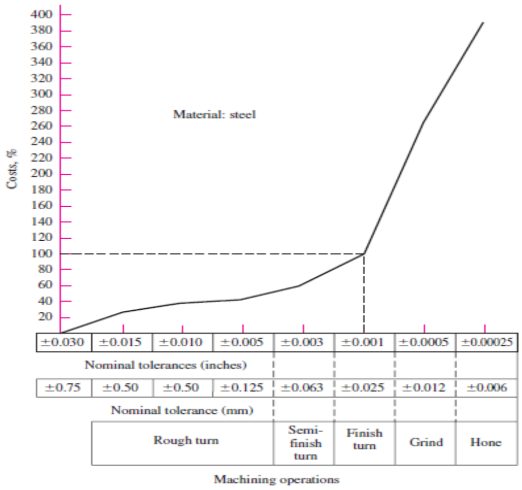
1. Role of Tolerance at Various Stage of Product[8]

As shown in above figure.1, tolerance plays vital role in these 4 stages. For the designing and inspection purpose, requirement of tolerance is less while for manufacturing and assembly, requirement of tolerance is higher. It is also recommended to determine the kind of tolerance required at various stages of product. For the design and assembly, tight tolerance is required while in manufacturing and inspection, lesser tolerance is required.



2. Requirement of Tolerance at Various Stage of Product[8]

1.2 Relationship between tolerance and cost



2. Relationship between tolerance and cost with respect to various machining operations[8]

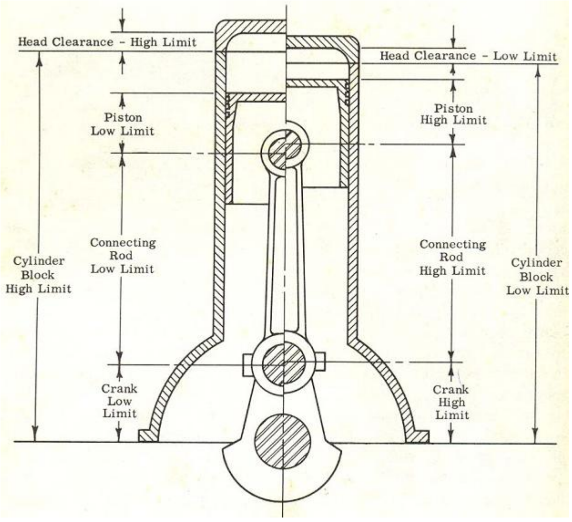
Here graph represents cost vs. nominal tolerances and machining operations. Steel material is considered here. Tolerances are considered in inches as well as in mm and various machining operations like rough turn, semi finish turn, finish turn, grind and hone. From the graph it is clearly understood that for the processes like rough turn and semi finish turn machining cost is not changing much for the large span of tolerance but as we move forward to finish turn and grind, critical tolerance is achieved but it increase the cost tremendously.
Therefore, it is concluded that for the range of 0.75 to 0.020 mm tolerance, the cost of machining tolerance is economical but then after it cost higher to achieve more precise tolerance.

1.3 Tolerance stack-up condition

In a mechanical assembly, individual components are seldom produced in unique sizes. Their functional dimensions can always be produced within some tolerance due to manufacturing and other limitations. Thus for a given set of tolerances associated with individual dimension, the tolerance accumulated on the assembly dimension needs to be estimated. This is usually called tolerance analysis. The accumulated tolerance on the assembly dimension must be equal to or less than the corresponding assembly tolerance specified by the designer based on the functional and assembly requirements. In the tolerance techniques, the different criteria used for establishing relation between accumulated tolerance on the assembly dimensions and the assembly tolerance is popularly called as tolerance stack-up conditions. Over the years various researchers have proposed different models for determining stack-up conditions [1].

1.4 Requirement of tolerance stack-up analysis

After having the idea about tolerance stack-up condition, it is very important to know that why tolerance stack-up analysis is so important. To understand it, consider the following figure.



3. Requirement of tolerance stack-up analysis[21]

Figure shows the cross section view of an IC engine which contains piston, crank, connecting rod, cylinder block and head.
All these parts are manufactured individually. Now if tolerance stack-up analysis is not performed then at the time of assembly such kind of difficult situation occurs as shown in figure.
Here all the parts are manufactured within tolerance limit but half of them are manufactured at high limit and half of them are at low limit. Therefore, even part is within tolerance limit, after assembly it will not work properly. Instead of being manufactured if tolerance stack-up analysis performed, it gives idea that within which range of tolerance, part can be manufactured and assembly will be easier.

1.4 Tolerance stack-up analysis methods

Tolerance stack-up analysis is specially required when no of components are attached in a single assembly. Therefore it plays a vital role in aerospace, marine, missile technology etc.
There are mainly 2 approaches for performing tolerance stack-up analysis. One is bottom to top tolerance stack-up analysis and second is top to bottom tolerance stack-up analysis.
From long years of span, various researchers have developed some methods for bottom to top tolerance stack-up analysis. As times went on some improvement also performed in these methods. Some of them are easy to use and some of them are difficult to use in realistic. All these methods have their own merits and limitations. Here some of method names are mentioned.
1. Worst case tolerance analysis
2. Statistical tolerance analysis
3. Computer aided tolerance
4. Consult standard tolerance analysis
5. Sensitivity analysis
6. Cost based optical tolerance analysis

Among all these methods, statistical tolerance analysis is performed by many ways. Here various ways for perform statistical tolerance is mentioned.

1. Linearization of assembly function using taylor series expansion
2. Method of system moments
3. Monte-Carlo simulation
4. Taguchi
5. Quadrature

Now detail discussion of some methods for bottom to top tolerance stack up analysis are described in literature review.

II. LITERATURE REVIEWED

Dr. Dinesh Shringi et al [1], analysis of new non-traditional tolerance stack up conditions is performed in this paper. A comparative cost analysis of different stack up models is solved by the combined simulated annealing and pattern search algorithm is determined in this paper. After explaining tolerance stack-up condition, 5 different models for stack-up analysis are explained along with equations like worst case, root-sum-square(RSS), modified RSS, spott's model, estimated mean shift(EMS). It is concluded that among all these models, worst case gives tighter tolerances which increase the manufacturing cost. To overcome this problem RSS model is introduced in which normal distribution parameter is included. But after getting the final value by RSS model it is divided by 3. Now the reason of being divided is not clearly mentioned here. To make this model more convenient, modified RSS model is introduced in which correction factor in introduced. Now value for the correction factor is different from the various research personnel. To overcome this trouble one new model is established as spott's model in which mean is taken of worst case and RSS. By considering a shaft bearing example, a cost comparison is made between all these models in which it determined that by using RSS cost is lesser than all other methods.

Mathieu Mansuy et al [2], performed a new calculation method for worst case tolerance analysis and synthesis in stack type assemblies. As name suggest new approach is considered for the stack assemblies without clearance and with clearance. It is concluded that there are so many factors that affect the stack-up analysis which assembly having clearance. It is also concluded that any kind of complex assembly can be converted into a single chain assembly with the help of this research work and can make relationship between functional condition and geometric tolerance by considering worst case. To make an assembly in a single chain influence coefficient is used which direct the chain and decide whether to make summation or subtraction of tolerances. Among all these influence coefficients which have the higher value is considered as reference.

Prof. Suyash Y. Pawar et al [3], tolerance stack up analysis and simulation using visualization vsa is performed in this paper. This paper represents how the manual methods for tolerance stack up analysis and simulation are different and less efficient than tolerance stack up analysis and synthesis using visualization vsa. From this paper it is concluded that tolerance stack-up analysis performed manually is not so efficient and realistic as in worst case, it is considered that all the tolerance are at their worst case simultaneously while in statistical tolerance analysis, assumption is made that tolerances are individual and have normal distribution. Therefore, RSS is used but in actual they are not perfectly correlated in machining. Also such kind of tolerance analysis is performed in one direction which does not represent perfect idea about 3 dimensional tolerances. But when tolerance stack up analysis is performed with visualization vsa, it distributes the tolerance in the descending order. Due to it, for the worst case higher tolerance is achieved than the RSS model as the size of component increase which leads to manufacturing cost down.

Luc Laperriere et al [4], tolerance analysis and synthesis using jacobian transforms is performed in this paper. Also mathematical relationship is established between small possible displacement of function element and functional requirement. This is expressed set of matrix form with a jacobian matrix. And it gives desired analysis relationship. It is concluded a relationship is established between functional requirement and functional element by using jacobian matrix. Here one tolerance chain is identified and then one nominal expression is derived which represents relative position and orientation between functional element in a pair and then converted in 4*4 homogeneous transforms. The position and orientation of functional elements are degraded using 3 orthogonal translations and 3 orthogonal rotations with each pair of functional element. This relationship is provided with jacobian matrix between each pair of both functional elements. Then to achieve the final result pseudo inversion of jacobian matrix is performed and desired functional requirement is obtained.

Paul Beaucaire et al [5], statistical tolerance analysis of over constrained mechanisms with gaps using system reliability method is performed in this paper. From the paper, it is concluded that the ultimate aim of this research is to calculate the probability of defects for over constrained mechanisms having gaps. For that probabilistic approach is used and it is very useful. In this research paper the values of functional characteristics are based on gaps. They are not based on part deviations as in other methods. Here random variables are used as deterministic variables. It is clearly explained that assembly with gaps is easier but functionality with gaps is complex. To overcome functionality issues, structural reliability domain is used. For that several contact points while making assembly are treated separately. They are dependent events. Here defect probability is calculated at designing phase with the help of FORM system method. Normally functional requirement is dependent on part deviation. So it will be the first step to reduce uncontrolled variable in the probability formulation. To calculate defects in part, two methods are appropriate meanwhile Lee and Woo approach is not so accurate and Monte-Carlo consumes more time.

Fangcai Wu et al [6], improved algorithm for tolerance allocation based on Monte-Carlo simulation and discrete optimization is performed in this paper. In this paper nonlinearly constrained tolerance allocation problems are considered and to handle them Monte-Carlo technique is used and to improve it genetic algorithm is used. From the paper, it is concluded that optimal ratio is achieved between the sum of the manufacturing costs and the probability of the respect of geometrical requirements and assembly requirements. For the real time application, traditional optimization algorithm is so complex that it is impossible to solve it as, function F is not available in analytic form. To implement Monte-Carlo simulation, geometric behavior should be defined. For that equation is to be developed in which part deviations, gaps and functional requirements are constrained.

Jinn-Tsong Tsai et al [7], an evolutionary approach for tolerance design is performed in this paper. Worst case tolerance design problems are solved with the help of sliding-level orthogonal differential evolution algorithm with a two level orthogonal array. For that two examples are considered, one is of 10 variables in which linear, non-linear, quadratic and polynomial forms are contained and second is of speed reducer design in which 7 variables and multiple non-linear engineering constraints are contained. From this paper, it is concluded that with the help of SLODEA2OA, effect of parameter variations and computation time is reduced. With the help of it, the obtained solution is within specified tolerance which makes vertex analysis result easier.

Somvir arya et al [8], application of Monte-Carlo technique for analysis of tolerance and allocation of reciprocating compressor assembly is performed in this paper. From this paper, It is concluded that normal distribution is considered for Monte-Carlo simulation. Skewed distribution is negative for all part dimensions and for all modules dimensions and the value of it is 0.3. Rejection rate is 0.21 which shows that the finally only 1% rejection rate is allowed.

III. CONCLUSION

The work presented here represents the overview of an important role of tolerance stack-up analysis for various types of assemblies.

Tolerance stack-up analysis is performed during designing phase. If analysis is not performed, it is difficult to achieve desirable assembly and also it increases manufacturing cost of components.

Cost based optical tolerance analysis is basically focuses on the cost of part manufacture by considering low cost. Easy way to achieve it is to manufacture a part at its resultant condition. Computer aided tolerance is used at the time of designing in which it is difficult to achieve final assembly tolerance when complex assemblies are there. Sensitivity analysis is basically used for electronics components. Taguchi method is used for quality, manufacturing and process engineering, not for dimensioning. Method of system moment is used for rotating mechanisms which generates moment while working. For the realistic problems, industries mostly use worst case method or RSS method.

Methods mentioned above are usually used for bottom to top tolerance stack-up analysis. They work on the base of finding probability of defect from no of parts. While applying bottom to top tolerance stack-up analysis, there are some known values of tolerance. These known values are based on standard tolerance chart and various types of fits. To implement these methods for bottom to top analysis, such kind of value is used as variables and final solution can be obtained. But when top to bottom tolerance stack-up analysis is performed, there is final assembly tolerance value is known only. Therefore, it is difficult to implement these methods. Therefore, there is no availability of any method to perform top to bottom tolerance stack-up analysis.

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