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DESIGN AND OPTIMIZATION OF MECHANICAL COMPONENTS AND ITS MECHANISM USING MONTE CARLO SIMULATION

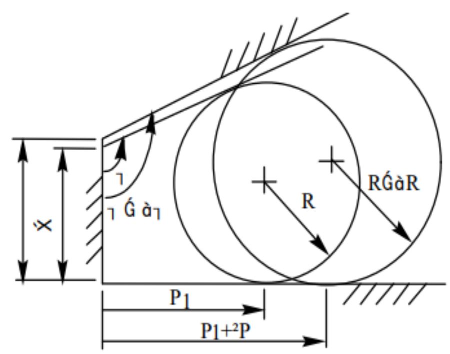
K. NIRMALA[1], Dr. K.SATISH BABU[2], Dr.K. HEMACHANDRA REDDY[3]
1(Research Scholar, JNTUA Ananthapuramu)
2 (Principal Ravindra College of Engineering for Women)
3 (Professor Dept of Mech JNTUA Ananthapuramu)

Abstract:

This paper studies in detail about the background and implementation of a MONTE CARLO SIMULATION based optimization with differential operator for optimization task of a few mechanical components, which are essential for most of the mechanical engineering applications. Like most of the other heuristic techniques, CARLO SIMULATION is also a population-based method and uses a population of solutions to proceed to the global solution. A differential operator is incorporated into the CARLO SIMULATION for effective search of better solutions. To validate the effectiveness of the proposed method, three typical optimization problems are considered in this research: firstly, to optimize the tolerance in cylinder, secondly, to optimize the volume in cylinder, and finally to optimize the weight of the cylinder. Simulation result on the optimization (mechanical components) problems reveals the ability of the proposed methodology to find better optimal solutions compared to other optimization algorithms.

Keywords — **Monte Carlo Simulation ,FEM.**

Introduction:
Assembly tolerance analysis is a key element in industry for improving product quality and reducing overall cost. It provides a quantitative design tool for predicting the effects of manufacturing variation on performance and cost, and promotes concurrent engineering by bringing engineering requirements and manufacturing requirements together in a common model. Assembly tolerance analysis involves determining how the components in an assembly interact with each other and how their variations affect assembly constraints. The simple two-component assembly consists of a cylinder in a groove.



Kinematic adjustment due to component size variations

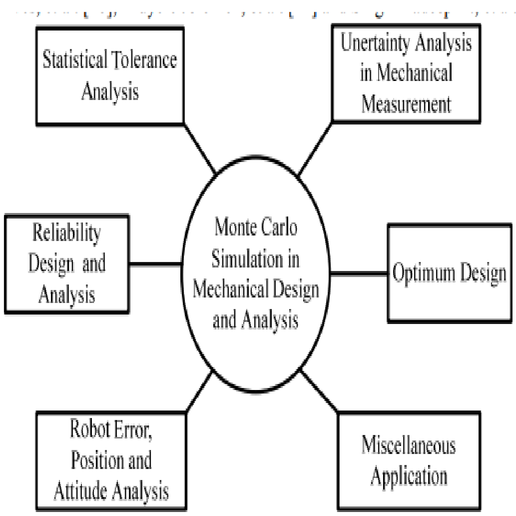
Assembly Tolerance Analysis Methods
Statistical tolerance analysis methods can be applied to geometric models of assemblies to predict the magnitude of variation in critical assembly features. The resulting statistical distributions may be used to estimate the percent rejects and to see if the assembly quality specifications will be met. Method developed for

statistical tolerance analysis of mechanical assemblies is Monte Carlo simulation.

Traditional Monte Carlo Simulation:

The Monte Carlo method performs assembly simulations using a random number generator which selects values for each manufactured variable, based on the type of statistical distribution assigned by the designer. These values are combined through the assembly function to determine a series of values of the assembly variable. This series is then used to find the first four moments of the assembly variable. Finally, a distribution matching the four moments can be used to determine the mean, standard deviation, and percentage of assemblies which fall outside the design specifications, or assembly reject rate.

Application of MC Simulation in Mechanical Engineering:



Application of MC method in mechanical engineering

Literature review:

1. Caflisch (2017), Monte Carlo is one of the most versatile and widely used numerical methods. It is independent of dimension, which shows Monte Carlo to be very robust but also slow. This paper describes application of Monte Carlo methods for integration problems, including convergence theory, sampling methods and variance reduction techniques. The points in a quasi-random sequence are correlated to provide greater uniformity. The resulting quadrature method, called quasi-Monte Carlo, has a good convergence rate.
2. Alexandrov et. Al. (2016), this paper describes, various approaches of designing scalable algorithms. The paper proposes implementations of parallel Monte Carlo algorithms and demonstrated their huge potential regarding speedup, fault-tolerance and scalability on a variety of applications. The paper also adds Future research possibilities, for example, investigate next generation algorithms for resilience and fault-tolerance in large-scale systems.
3. Mehrdoust and Vajargah (2016), This paper describes two types of pricing options in financial markets using quasi Monte Carlo algorithm with variance reduction procedures. Authors have evaluated Asian-style and European-style options pricing based on Black-Sholes model. The paper concludes that control varieties Monte Carlo is efficient for both Asian & European style.
4. Zhao et.al. (2015), this paper describes the importance of sampling Monte Carlo methods for pricing options. The classical importance sampling method is used to eliminate the variance caused by the linear part of the logarithmic function of payoff. The variance caused by the quadratic

part is reduced by stratified sampling. By eliminating both kinds of variances just by importance sampling. The corresponding space for the eigen values of the Hessian matrix of the logarithmic function of payoff is enlarged.

5. Huseby et. Al (2014), the paper shows how Monte Carlo methods can be improved by putting constraints on a variable or vector. It shows that Different choices of variables to condition may lead to different approaches. Paper shows that simulating from the conditional distribution can be as efficient as simulating from the unconditional distribution. Paper presents a simulation algorithm which enables us to estimate the entire system reliability polynomial expressed as a function of the common component reliability. According to the authors if component reliabilities are not too different from each other, a generalized version of the improved conditional method can be used in combination with importance sampling.
6. Bihani (2014), this paper proposes a new approach to Monte Carlo simulation of operations thereby optimizing multi -server operations. Paper analyses the Monte Carlo methods against the deterministic methods. Monte Carlo methods are a broad class of computational algorithms that depend on repeated random sampling to obtain numerical results. They are often used in physical and mathematical problems and are most suited to be applied when it is impossible to obtain a closed-form expression or infeasible to apply a deterministic algorithm. Monte Carlo methods are mainly used in: optimization, numerical integration and generation of samples from a probability distribution. Monte Carlo methods are especially useful for simulating systems with many coupled degrees of freedom; some of the examples are fluids, disordered materials, strongly coupled solids, and cellular structures.
7. Krishna et. Al. (2013), this paper analyses error correlation through concepts of error region, channel signature, and correlation distance. This framework provides a deeper insight into joint error behaviors in high- speed links, extends the range of statistical simulation for coded high-speed links, and provides a case against the use of biased Monte Carlo methods in this setting.

Methodology:

Reliability Design and Analysis: Many parameters are stochastic variables, so the probability model is always utilized in the reliability design and analysis. The MC simulation is feasible to solve this problem.

Modeling of tolerance allocation:

The analytical modeling of assemblies provides a quantitative basis for the evaluation of design variations and specification of tolerances. An important distinction in tolerance specification is that engineers are more commonly faced with the problem of tolerance allocation. In tolerance allocation, the assembly tolerance is known from design requirements, whereas the magnitude of the component tolerances to meet these requirements is unknown. The available assembly tolerance must be distributed or allocated among the components in some rational way.

Simulation of tolerance analysis:

Geometrical deviation or variation is defined by a displacement between two any surfaces in a mechanical system. Each real surface can be modeled by a substitution surface. The model of substitution surfaces is based on the assumption that form defects are generally negligible. Generally, the relative position (position, orientation) between any two surfaces in the mechanical system is determined by the relative position between two substituted surfaces. The model will not be selected for surfaces modeling when dealing with form defects.

PERFORMANCE ANALYSIS USING MONTE CARLO SIMULATION

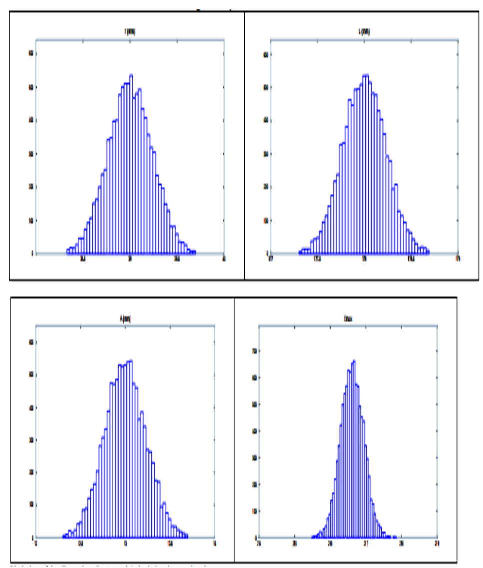
The Monte Carlo simulations were conducted with the aim of investigating ICP performance in terms of several criteria that are considered to be of importance in inspection related applications. These criteria are: (a) mean square error (MSE), (b) maximum error (important for inspection), (c) average error, (d) confidence in the transformation parameter estimates, (e) number of iterations required to achieve given accuracy. The simulations analyzed the dependence of these performance measures with respect to the following factors: (a) number of random measurements on the object, (b) measurement of noise (assumed to be Gaussian with known standard deviation, j), (c) initial misalignment (three-dimensional translation and rotation), (d) fineness of approximation of the NURBS model.

Description and conduct of the Monte Carlo simulation:

Data sets were obtained by performing simulation of CAD based inspection. Because of the large number of data sets required, it was decided to conduct all trials on the basis of a single real object, which was carefully chosen to contain various geometric characteristics that would be representative of different situations.

Surfaces modeling in a tolerance analysis approach:

The main objective of the proposed difference surface-base method is to simplify the tolerance analysis approach by considering only superimposed form defects of the two cylinders when assessing the contact position. The distance can be thus computed between the points of the difference surface and one of the perfect cylinders



Variation of the dimensions L, A, r and Cf in their tolerance bands

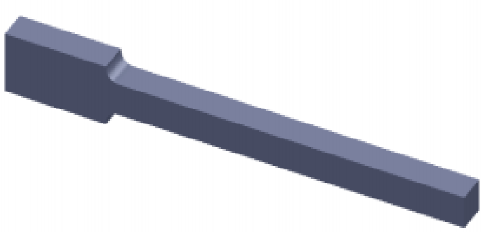
RESULTS:

SIMULATION FATIGUE TESTS:

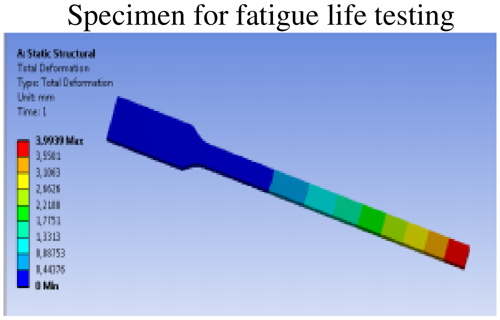
Fatigue life predictions using finite element analysis:

The finite element analysis is a numerical method for solving problems of engineering and mathematical physics and it is useful for problems with complicated geometries, loadings, and material properties where analytical solutions cannot be obtained.

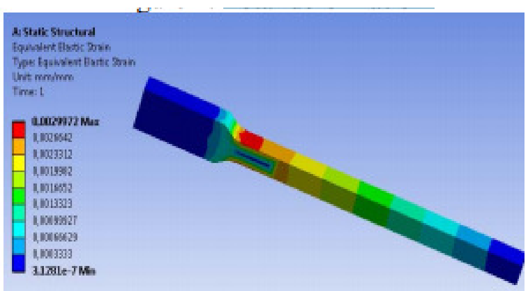
Fatigue life simulation is based on a single static structural FEA result and an expected loading history while the part is in use. Engineers have used the ANSYS Fatigue module for simple geometries and loadings for many years. For the majority of realistic geometries and real life loading, ANSYS nCode Design Life is the ideal choice.



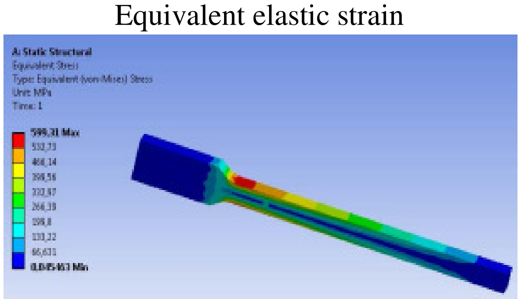
Specimen for fatigue life testing



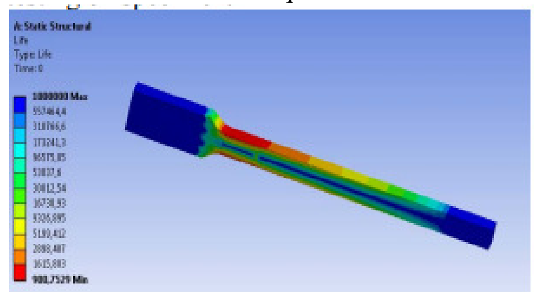
Total deformation



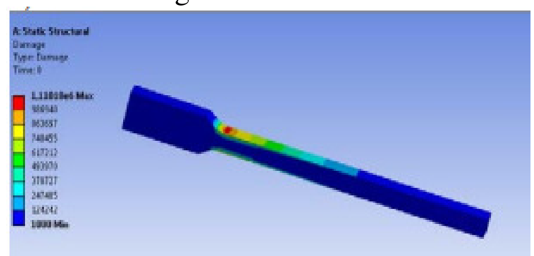
Equivalent elastic strain



Distributions of Equivalent Stress



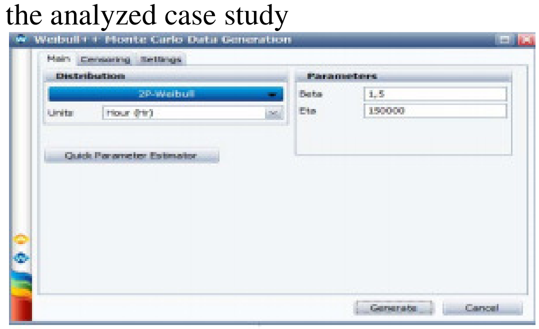
Fatigue life estimation



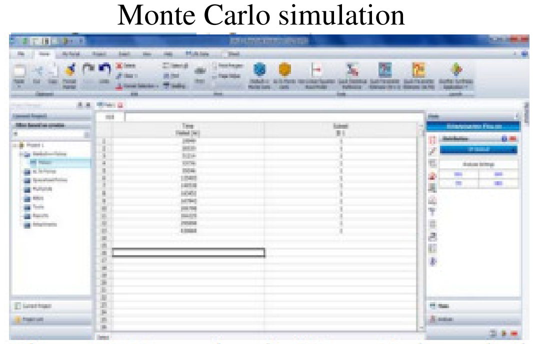
The distributions of Fatigue Damage

Fatigue life predictions using Monte Carlo method:

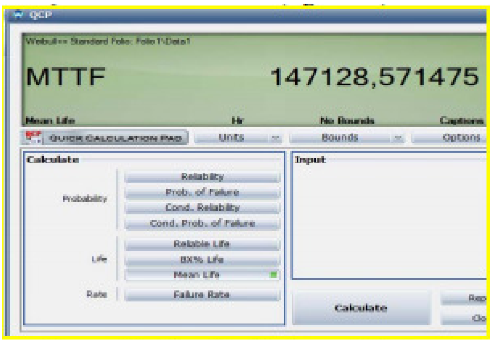
Using the Monte Carlo method, we simulated N stages of a mechanical component with the help of a statistical distribution (Weibull) which are suited to the analyzed case study



Monte Carlo simulation



Data using the Monte Carlo method



The distributions of Fatigue Damage

Conclusions:

The study shows that the number of cycles to failure from finite elements analysis, the simulation with the Monte Carlo method and the data from the fatigue testing. We can observe that, by using the simulation methods (FEA and Monte Carlo) of fatigue life, can obtain good results even in early stage Product Design and Development.

Finally, in the absence of readily available analytical techniques, Monte Carlo simulation was shown to be a good tool for assessing the registration performance in a given situation. The simulation process described in the paper can be readily performed, in full or in part, to produce definitive results about registration of any given object using any given measurement sensor.

References:

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