

FIXTURE DESIGN OPTIMIZATION USING GENETIC ALGORITHM-A REVIEW

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ABSTRACT: Fixtures are used to locate, hold and support workpieces in manufacturing operations such as machining, inspection, and assembly. Researching the possibilities for fixture design optimization has been in the sphere of interest of a number of authors worldwide for a longer period. Fixture design process and fixture design technique with conventional methods have been obsolete. Genetic Algorithm method has been selected as optimization of fixture design. This paper presents a brief review of Fixture Design optimization and Genetic Algorithm integration in terms of fixture layout, clamping position and part deformation. Also Introduction of Genetic Algorithm with applications, pros and cons are described.

KEYWORDS: Fixturing Principles, Fixture Design Technique, Genetic Algorithm (GA), Applications, Pros & Cons of GA.

1. INTRODUCTION

The challenge of modern machining industries is mainly focused on the achievement of high quality, in term of work piece dimensional accuracy, surface finish, high production rate, less wear on the cutting tools, economy of machining in terms of cost saving and increase of the performance of the product with reduced environmental impact.

A fixture is a device for locating, holding and supporting a workpiece during a manufacturing operation. Fixtures are essential elements of production processes as they are required in most of the automated manufacturing, inspection, and assembly operations [1].

Fixture design mainly done with conventional methods. Fixture design has much to do with experience, which the younger engineers generally have been unable to acquire. It can take engineers many years to learn the nuances of the craft. With the development of Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM), product design and machining programming have been generally computerized. Fixture design and manufacturing is costly due to tight tolerance and restricted machining operations.

However, they work effectively but are unlikely to be optimized to satisfy the demands of modern manufacturing.

2. FIXTURE DESIGN PRICIPLES & REQUIREMENTS

The fundamental principles of basic fixture design, which have been actually used in manual fixture design. These principles can be categorized as follows [2];

1) Supporting and Locating Principles

The main purpose of this section is to describe the "fixturing criteria" that ensure the precise locating and rigid supporting of the workpiece under various circumstances. There are a total of 12 (2 x 3 x 2) linear and rotational movements along the x-, y- and z-axes, including both positive and negative directions (see Fig.1). Usually, supporters and locators restrict at least nine movements, with the remaining three possible movements constrained by clamps.

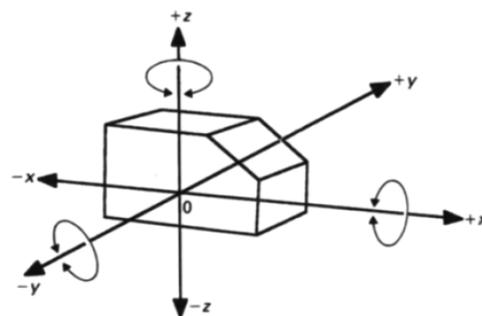


Fig.1 12 degrees of movement [2]

2) Clamping Principles

Clamping is used to restrict the possible movement of a workpiece that is not bound by supports and locators (usually three or fewer degrees of freedom need to be constrained). The general clamping principles are reviewed below according to the clamping direction with respect to the workpiece set-up.

Requirements

A machining fixture design, in general, should satisfy the following four major requirements:

- 1) Locating accuracy
- 2) Total restraint
- 3) Sufficient rigidity
- 4) No interference

3. FIXTURE DESIGN PROCESS

Fixture design can be divided into four separate steps, setup planning, fixture planning, fixture unit design, and verification [3]. A chart of these steps in more detail is shown below in Fig.2.

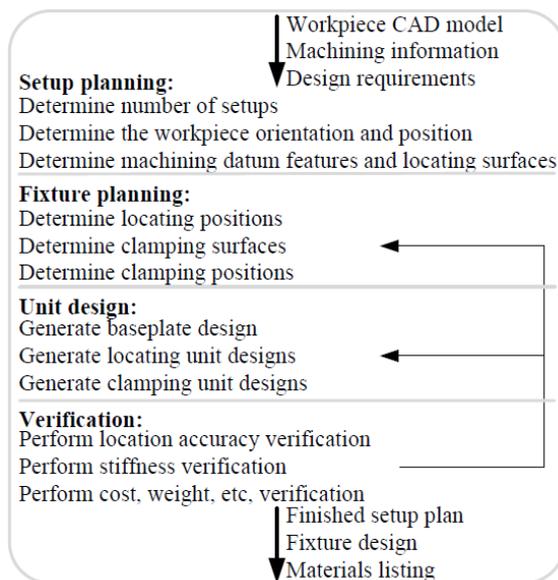


Fig.2 Process of Fixture Design [4]

4. FIXTURE DESIGN TECHNIQUE

The complete planning, design and documentation process for a fixture consists, in the widest sense, of three phases as follows [5];

- 1) Design Preplanning,
- 2) Fixture Design and
- 3) Design Approval

In this session mainly focus on Design Preplanning (Sequence of Operations) and Fixture Design (Axiomatic Design) as Design Approval is done at company level.

1) Sequence of Operations

It is not purpose of this paper to deal with planning process; however there may be cases where an operations plan is not available to the designer and in such instances his first step may be to compose the operations sequence. It is an absolute necessity to have the sequence finalized prior to fixture design.

There exists a set of general rules for selecting the sequence of operations. They are simple and logical, and almost universal; exceptions to these rules may exist but they are rare and usually occur only under special conditions. These rules are [5];

1. Rough machining is done before finish machining, followed by grinding if required.
2. To allow for natural stress relief, all roughing operations should be done before any finishing machining is started.
3. There may, however, be cases where the part in the completely unmachined condition has no suitable clamping surfaces for heavy cut.
4. Another equally important consideration is the avoidance of broken edges in castings and burrs on ductile parts.
5. The rule can be stated in its generality as follows; Surface machining comes before depth machining.

2) Axiomatic Design

Axioms are well accepted truths which provide the basis for decision making in the design process. If a design solution is developed applying the appropriate axioms should follow that the design criteria are satisfied. Good workpiece control is necessary for the workpiece design specification to be met. The principles are re-introduced here in simplified form and presented in the form of axioms [6].

Workpiece Control

Workpiece control is considered in three headings;

- geometric control
- dimensional control
- mechanical control

5. GENETIC ALGORITHM

Genetic Algorithm (GA) is numerical optimization mechanisms based upon the mechanics of natural selection as exhibited in nature [7]. Evolutionary computing was introduced in the 1960s by I. Rechenberg in the work "Evolution strategies". This idea was then developed by other researches. Genetic Algorithms (GAs) was invented by John Holland and developed this idea in his book "Adaptation in natural and artificial systems" in the year 1975. Holland proposed GA as a heuristic method based on

“Survival of the fittest”. GA was discovered as a useful tool for search and optimization problems [8]. The Genetic Algorithm Vocabulary is given (Table 1). In contrast to local search methods, genetic algorithms are based on a set of independent computations controlled by a probabilistic strategy. This is a simulation of natural selection of best individuals inside successive generations. Following the classical terminology, a solution for a problem under consideration is called an individual. The set of considered individuals is called a population.

| Genetic Algorithm | Explanation |
|---------------------------------|-------------------|
| Chromosome (String, Individual) | Solution (Coding) |
| Genes (Bits) | Part of solution |
| Locus | Position of gene |
| Alleles | Values of gene |
| Phenotypes | Decoded solution |
| Genotypes | Encoded solution |

Table 1 Genetic Algorithm Vocabulary [9]

Each individual has one chromosome string encoding its data characteristics. Then, a chromosome is a sequence of alleles representing one quantum of information, such as bit, digit, and letter etc. & is alternative data representation requires coding and decoding in order to exchange solutions with the nominal object space. The flowchart showing the process of GA is as shown in Fig.3.

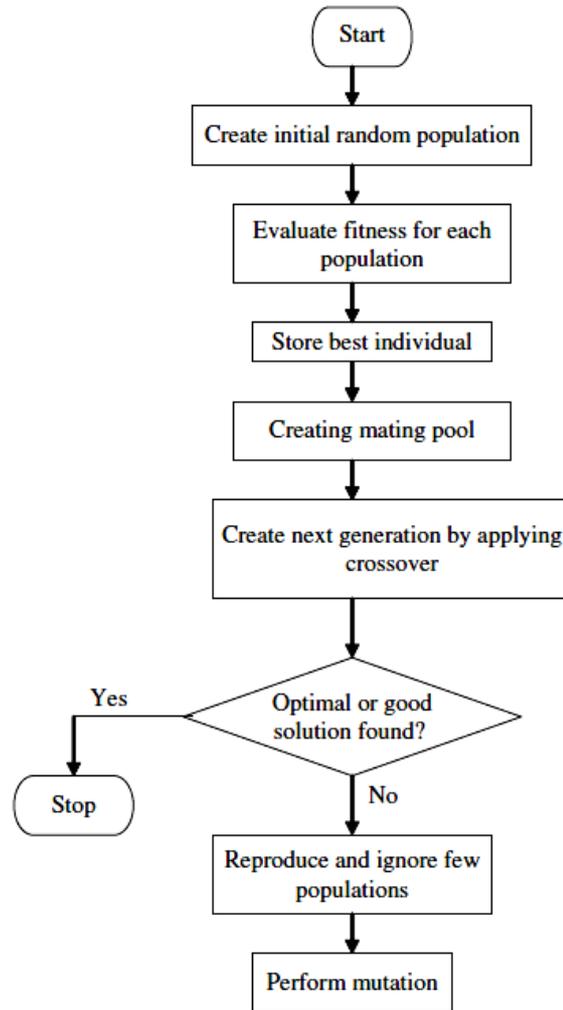


Fig.3 Flowchart of Genetic Algorithm [8]

6. GENETIC ALGORITHM METHODOLOGY

1) Initialization

GA operates on a number of potential solutions, called a population, consisting of some encoding of the parameter set simultaneously. Initially many individual solutions are randomly generated to form an initial population. The population size depends on the nature of the problem, but typically contains several hundreds or thousands of possible solutions. Traditionally, the population is generated randomly, covering the entire range of possible solutions (the search space). Occasionally, the solutions may be “seeded” in areas where optimal solutions are likely to be found.

2) Objective and Fitness Functions

The objective function is used to provide a measure of how individuals have performed in the problem domain. In the case of a minimization problem, the most fit individuals will have the lowest numerical value of the associated objective function. This raw measure of fitness is usually only used as an intermediate stage in determining the relative performance of individuals in a GA. Another

function, the fitness function, is normally used to transform the objective function value into a measure of relative fitness, thus:

$$F(x) = \frac{f(x)}{g(x)}$$

where f is the objective function, g transforms the value of the objective function to a non-negative number and F is the resulting relative fitness.

3) Selection

During each successive generation, a proportion of the existing population is selected to breed a new generation. Individual solutions are selected through a fitness-based process, where fitter solutions (as measured by a fitness function) are typically more likely to be selected. Certain selection methods rate the fitness of each solution and preferentially select the best solutions. Other methods rate only a random sample of the population, as this process may be very time-consuming.

Most functions are stochastic and designed so that a small proportion of less fit solutions are selected. This helps keep the diversity of the population large, preventing premature convergence on poor solutions. Popular and well studied selection methods include roulette wheel selection and tournament selection. Selection can be considered to consist of three phases [10];

1. Determination of the expected number of trials an individual can expect based on its relative fitness level.
2. Assignment of copies to the intermediate group ("Roulette Wheel" method).
3. Random partner allocation of intermediate group members.

4) Crossover(Recombination)

In nature, the genetic makeup of new species members (i.e. offspring) is a combination of chromosomes inherited from the offspring's parents. The genotype of both parents consists of a complete set of alleles, each of which provides for a specific manifestation of the phenotypical attribute or feature that the particular allele governs. Offspring in general, only inherit alleles from either one parent or the other for each phenotypical attribute and in this way the genotype of the offspring consists of a mixture of inherited alleles from both parents, thus giving expression to a completely new phenotype. Evolution biases the selection of inherited alleles in the offspring genotype such that in each instance of allele inheritance from parents, the "stronger" allele, of the two, is selected. A stronger allele is defined as one which will give an expression to the phenotypical attribute which is better suited to the species environment [11].

5) Mutation

In natural selection, mutation is a stochastic process, which results in the genetic change of an allele within a chromosome. A new expression is therefore given to the phenotypical attribute governed by the chromosome, and more specifically, the allele. The consequence of the allele mutation may result in a phenotype which, relative to other phenotypes of the species, is less suited to its environment; more suited to its environment or which is equally suited to its environment (i.e. the mutation has no effect).

Usually considered as a background operator, the role of mutation is often seen as providing a guarantee that the probability of searching any given string will never be zero and acting as a safety net to recover good genetic material that may be lost through the action of selection and crossover [7].

6) Reinsertion

Once a new population has been produced by selection and recombination of individuals from the old population, the fitness of the individuals in the new population may be determined. If fewer individuals are produced by recombination than the size of the original population, then the fractional difference between the new and old population sizes is termed a generation gap. In the case where the number of new individuals produced at each generation is one or two, the GA is said to be steady-state or incremental. If one or more of the most fit individuals is deterministically allowed to propagate through successive generations then the GA is said to use an *elitist strategy* [11].

7. APPLICATIONS, PROS & CONS OF GA

A few applications of GA are as follows:

- Nonlinear dynamical systems–predicting, data analysis
- Robot trajectory planning
- Evolving LISP programs (genetic programming)
- Strategy planning
- Finding shape of protein molecules
- TSP and sequence scheduling
- Functions for creating images
- Control–gas pipeline, pole balancing, missile evasion, pursuit
- Scheduling–manufacturing, facility scheduling, resource allocation
- Machine Learning–Designing neural networks, both architecture and weights, improving classification algorithms, classifier systems
- Signal Processing–filter design
- Combinatorial Optimization–set covering, traveling salesman (TSP), Sequence scheduling, routing, bin packing, graph coloring and partitioning

- Design–semiconductor layout, aircraft design

The pros of GA are as follows:

1. Parallelism
2. Liability
3. Solution space is wider
4. The fitness landscape is complex
5. Easy to discover global optimum
6. The problem has multi objective function
7. Only uses function evaluations.
8. Easily modified for different problems.
9. Handles noisy functions well.
10. Handles large, poorly understood search spaces easily
11. Good for multi-modal problems Returns a suite of solutions.
12. Very robust to difficulties in the evaluation of the objective function.
13. They require no knowledge or gradient information about the response surface
14. Discontinuities present on the response surface have little effect on overall optimization performance
15. They are resistant to becoming trapped in local optima
16. They perform very well for large-scale optimization problems
17. Can be employed for a wide variety of optimization problems

The cons of GA are as follows:

1. The problem of identifying fitness function
2. Definition of representation for the problem
3. Premature convergence occurs
4. The problem of choosing the various parameters like the size of the population, mutation rate, cross over rate, the selection method and its strength.
5. Cannot use gradients.
6. Cannot easily incorporate problem specific information
7. Not good at identifying local optima
8. No effective terminator.
9. Not effective for smooth unimodal functions
10. Needs to be coupled with a local search technique.
11. Have trouble finding the exact global optimum
12. Require large number of response (fitness) function evaluations
13. Configuration is not straightforward

8. FIXTURE DESIGN AND GENETIC ALGORITHM

Yeung, Ka Yiu and Chen, Xun proposed an application of genetic algorithms (GA) developed for the optimisation of fixture locator positioning for 3D freeform. The preliminary implementation is introduced to demonstrate the ability of GA in

automated fixture design [12]. Afzeri, M. Konneh, A.G.E. Sutjipto, Yulfian Aminanda presents the hybrid optimization algorithm to obtain an optimum clamping configuration of pin type fixture. Genetic and Particle Swarm Optimization (PSO) algorithms are utilized serially for determining the minimum workpiece deformation. Pin fixture with array arrangement in two opposite side supports the workpiece through clamping and friction force [13]. N. Kaya presented optimization of support, locator and clamp locations is a critical problem to minimize the geometric error in workpiece machining. In this paper, the application of genetic algorithms (GAs) to the fixture layout optimization is presented to handle fixture layout optimization problem. A genetic algorithm based approach is developed to optimise fixture layout through integrating a finite element code running in batch mode to compute the objective function values for each generation [14].

Kulankara Krishnakumar proposed optimization of fixture layout is a critical aspect of machining fixture design and presented a fixture layout optimization technique that uses the genetic algorithm (GA) to find the fixture layout that minimizes the deformation of the machined surface due to clamping and machining forces over the entire tool path [15]. Again K. Krishnakumar presented the paper deals with application of the genetic algorithm (GA) for fixture layout and clamping force optimization for a compliant workpiece. An iterative algorithm that minimizes the workpiece elastic deformation for the entire cutting process by alternatively varying the fixture layout and clamping force is proposed [16].

9. CONCLUSION & FUTURE SCOPE

Based on previously conducted analyses, literature information and contacts with the experts in the field in question, it can be concluded that complete fixtures design optimization is one of more significant and complex tasks. Genetic algorithm is a probabilistic solving optimization problem which is modeled on a genetic evaluations process in biology and is focused as an effective algorithm to find a global optimum solution for many types of problem.

In future development of an optimization model for fixture design with machining parameters and influence of various constraints can be checked and it can be integrated with Computer Aided Process Planning (CAPP).

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