Hybrid Optimization of Pin type fixture Configuration for Free Form Workpiece

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Abstract

This paper presents an automatic mechanism using pin type fixture for holding a workpiece during machining process. The hybrid optimization algorithm is introduced to obtain the optimum configuration of pin type fixture. Combination between Genetic Algorithms (GAs) and Particle Swarm Optimization (PSO) algorithms is enable to determine optimum clamping respect to minimum workpiece deformation. Spherical type pin fixture with array arrangement in two opposite side comforms geometry of workpiece through with two supporting action. Deformation as efect of clamping force and friction slip are predicted by simulation of pin-workpiece clamping model and analyzed by Finite Element methods. Maximum deformation and slip condition are evaluated by building the parametric script of the model. Parameters of the model is assigned by the algorithm through iteration process. Satisfies clamping arrangement to minimize the deformation and prevent the slip is evaluated using GAs to arrange the pin configuration. PSO is further applied based on the result of GAs for obtaining global optimum of objective function. Result of the evaluation shown that the optimization using two algorithms could achieve the beter position and clamping configuration for variety of workpiece geometry modeled using CAD software.

Keyword: Optimization, Pin Fixture, Genetic Algorithm, Particle Swarm Optimization, Finite Element

1. INTRODUCTION

Selection of best fixture for holding variety of workpiece geometry is tending to time consuming and costly. Pin type fixture is an alternative for free form geometry where only single fixture for many workpiece design. Reconfigurable fixturing is becoming a necessary component in order to reduce the cost of fixture development. Comparing to the development of new fixturing system, pin type fixture have possibility to reduce the production cost significantly especially for low repetitive machining. Various geometry of the parts could be hold by a pin type fixture with certain clamping configuration. Pin fixture has been investigated as an attachment that used for setup free on machining process with capability to hold variety of part geometry [1]. A part hold by setup free attachment could be machined completely on one process by using long round bar as raw material.

Main criteria of the fixture for holding the workpiece are should maintain the workpiece within acceptable accuracy and stability during machining process. Every point of the fixture should in contact with the workpiece. Proper workpiece holding and clamping location are important to machining quality in terms of precision, accuracy and surface finish of the part.

A simulation model through FEA tools that evaluate the performance of the pin fixture-workpiece model will help the engineers to determine the better configuration and save lead time for workpiece setup. The technique in simulation is to represent every point where the pins are in contact with the workpiece using springs element.

For a pin type fixture with array arrangement, holding of the workpiece is performed by clamping force in axial direction and friction force in tangential direction. Amount of friction force is the function of clamp in axial force and coefficient friction. Friction force should strong enough to prevent slip of the workpiece. However, increasing the friction force only can be done by increasing the clamping force which may affect to the part quality. In this paper, Finite Element modeling of pin fixture and workpiece system for evaluation of workpiece deformation and slip detection is discussed. Ansys software has been used for calculating the deflection and slip for various pin configuration and cutting forces. Spring model is used instead of pin with contact behavior for detection of slip. Parametric script file is built for accepting a variety of modeling input data.

Fig. 1 shows a prototype of array pin type fixture developed in the laboratory. There are a number of 45 pins with 10 mm diameter in one side. Two types of pins, flat and spherical type are provided for clamping the variety geometry of workpiece material. Distance between pin is 15 mm. In this paper, only presents the variation of sixteen pins.

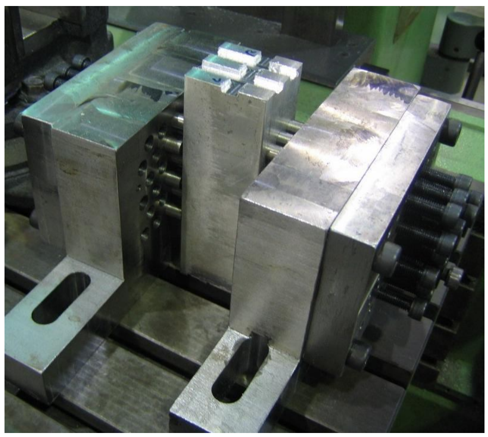

FIGURE 1: Prototype of Pin Type fixture

2. LITERATURE REVIEW

Pin type reconfigurable fixture has been considered as an alternative device for holding the irregular workpiece geometry for machining. Many researches for fixture design have been considered in recent year. Utilization of FEA for fixture modeling and simulation technique has been published in many literatures.

FEA was used as a platform for cost-effective and accurate simulation of complex dynamic fixture–workpiece behavior [2] [3]. Calculation of deflections using FEA for the minimization of the workpiece deflection at selected points as the design criterion also introduced [4]. Commercialized FEA software, Ansys, is utilized to verify fixture design integrity and the optimization analysis [5].

Genetic Algorithm is useful technique in engineering for problem solving optimization. Optimization technique using finite element modeling for analysis and verification of optimal fixturing configurations with methods of force closure also investigated [6].

Locating of clamping position using genetic algorithm has been investigated by several researchers [7] [8].

Fixture layout optimization has been implemented using Matlab GA tool and NASTRAN for Finite Element Model. Determination of optimal fixture configuration design using GA and Nastran has been applied for sheet metal assembly [9].

Most of the studies are to develop new fixture layout for new design of part where 3-2-1 approach used for the design. However, attention focused on the pin type fixture still limited where the friction slip is considered as the main holding factor. In application of Finite Element Analysis (FEA), the model to analyze a fixture–workpiece system is completely rigid [10]. In the Pin type fixture system, rigidity of the pins causes inaccuracy on clamping. For various cases, Evolutionary algorithms are not possible to obtain optimal solution. Hybrid methods are introduced in this paper in order to find the best fixturing condition.

3. METHODOLOGY OF GENETIC ALGORITHMS

GAs is an evolutionary algorithm for optimization of a system. There are several major ways for optimization technique which different that traditional gradient. Genetic Algorithm is an optimization technique work with a coding of the design variable. Many different design points are evaluated during iteration where it is a better way instead of sequentially moving from one point to the next. GA which uses probabilistic transition rule to find new design point only need a fitness as a objective function to find optimum condition. GAs approach is suitable for problem which doesn't have well defined mathematical definition between the function and variable. Evolutionary algorithms are known the best problems solution tool applied where optimality of the system difficult to be tested.

Basic procedure of GA is as following step. Firstly generate initial population of chromosome randomly. Secondly, evaluate the fitness function for each chromosome in the population. Thirdly, Satisfies condition for new generated population is then tested. Reliability of each chromosome is evaluated based of the fitness value. Forth step is generating new population by reproduction, crossover and mutation operation. Reproduction is selection of two parent chromosomes from population according to their fitness. Crossover is a probability to form a new offspring (children). Offspring will an exact copy of parent when no crossover was performed. Mutation is a probability of new spring at each locus. The last step is to use new generated population for further run of algorithm as conducted from second to fourth step.

Best value of number iterations and mutation probability has to be selected to achieve the optimum objective function. For several model cases, this value should be chosen by trial and error. In order to improve the result of GA evaluation, hybrid evaluation is utilized by combining GA and PSO. An optimal solution resulting of GA evaluation further can be processed using PSO algorithm. There are four variables are used for evaluation. Two variables for the pin left and right side and another two are workpiece position in y and z. Pins configuration for left and right side are determined by GA to the best configuration while optimum positions around the best configurations are determined using PSO algorithm.

4. CLAMPING FORMULATION

Pin type clamping fixture should satisfy the functional requirement such as centering, locating, orienting and supporting [11]. Deformation due to the clamping force influences the accuracy of the workpiece during machining. When clamp is actuated this causes the deformation error. Maximum deformation should be in the range of tolerable accumulative error. Pin type reconfigurable fixture has two side array pin with equal number in each side. One side is assigned as locator while another side as clamp. Evaluation of clamping pin is to determine the better number of pins for a setup and preventing the slip.

Pins configuration is determined base on clamping stability and deformation on a pin-workpiece model. There are two forces act to restrain the workpiece; axial clamping force and friction force. Direction of axial forces is normal to workpiece surfaces. Friction force restrains the workpiece in tangential direction with two vector directions, x_i and y_i. Pin–workpiece deflection model for spherical-tipped pins is assumed to be given by that of a spherical-tipped cylindrical punch indenting an elastic surface.

In contact pins are modeled with three springs k_{xi}, k_{yi} and k_{zi} as proposed [12]. Variables k_{xi}, k_{yi} are stiffness in tangential direction and k_{zi} is stiffness in pin axial direction. Value of spring constant (k) is dependent to the pin length which may be different for variety geometry of workpiece. Constant clamping force using hydraulic is considered during evaluation. All clamping pins are actuated with the same force. Objective function of the model is deformation of the workpiece which is evaluated by Finite Element analysis.

The contact force-displacement for a pressed spherical-tipped pin element over a curved workpiece surface is derived as follows. Spherical-tip deflection for axial and radial direction is defined as [13]:

$$\delta_z = \left[\frac{9F_a^{\ 2}}{16R(E^*)^2} \right]^{1/3} \qquad (1)$$

and

$$\delta_j = \frac{Q_j}{8a}\left(\frac{2-v_w}{G_w} + \frac{2-v_f}{G_f} \right) \qquad (2)$$

where, R = 1/(R$_w$ + 1/R$_p$)-1 is the relative curvature at the contact. R_w and R_p is the local radius of workpiece surface and tip radius of fixture element respectively. Variable E* is composite elastic modulus defined as $1/E^* = (1 - v_w^{2}) / E_w + (l — v_p^{2})/E_p$. Variables v, and G represent the Poisson's ratio, and shear modulus of the material, respectively; the subscripts w and p refer to the workpiece and pin fixture elements, respectively. Variable is the radius of the contact region defined as a = (3PR/4E*). Q_j is friction force calculated by coefficient of friction multiply by pin axial force. Spherical tip deflection is considered by assuming structure of fixture body is rigid.

Linearization of contact stiffness in normal direction for spherical tipped pin fixture element with phenomenon sphere indenting on planar surface is defines as [10]

$$K_z = 13.95\left[\frac{16R_p(E^*)^2}{9} \right]^{1/3} \qquad (3)$$

Length of the pins which is the distance from contact position to the pin host will different due to variation of workpiece geometry. Compliant of the pin have significant contribution for clamping stability. Pin length factor is modeled in addition of pin contact tip. Contact stiffness of pin is modeled as a serial spherical pin combined with a cylindrical beam fixed at one end and sheared at the other.

$$K_{bt} = \frac{E\pi R_p^{\ 2}}{L} \qquad (4)$$

$$K_{pt} = \left[\frac{1}{K_z} + \frac{1}{K_{bt}} \right]^{-1} \qquad (5)$$

L is the distance from pin host to sphere center. For the model evaluated in this research, pin stiffness axial (K_z) and radial (K_{pt}) are determined at the time the model is created and assumed constant for variation of forces and workpiece deformations.

Axial reaction force is calculated from the result of deformation in axial direction:

$$F_{am} = \delta 2_z \ K_n \qquad (6)$$

and tangential force of pin is defined by Coulomb friction law of pin :

$$Q_j = \mu \ F_{am} \qquad (7)$$

5. MODEL FOR FREE FORM GEOMETRY

Free form geometry may be designed using variety of geometrical formulations. A part model may be created using a surface equation such as B-Spline or NURBS or combination between Surface and Features base modeling.

Contact model between pin and workpiece surface is defined by three vectors; one normal vector and two tangential vectors. Normal vector is obtained by interfere operation between pin and workpiece. Vector is determined by the direction from contact point and center of pin. Fig.2 shows CAD simulation to get contact normal vector.

A tangential vector represents the spring model for restrain the workpiece from slip. First vector is defined as the vector parallel to x axis of world coordinate system. Another vector is the cross product of normal and first tangential vectors.

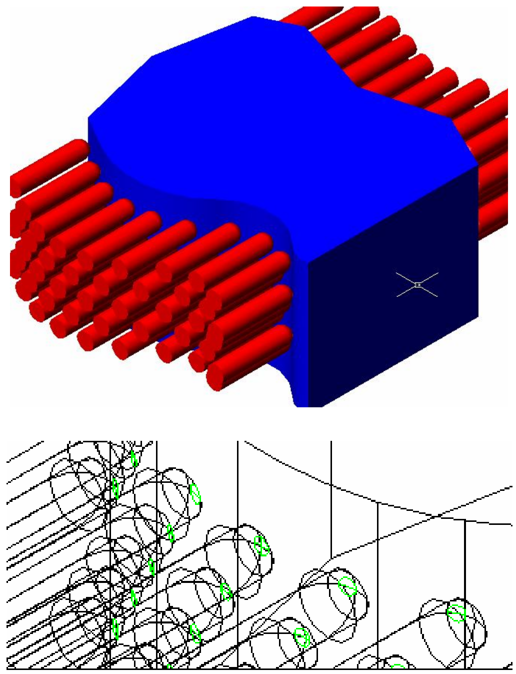

FIGURE 2: Solid Interfere evaluation to obtain Contact and surface normal

6. FINITE ELEMENT MODELING

Finite element analysis using Ansys software is utilized to determine the deformation during clamping. Workpiece model is imported from CATIA V5 CAD software and SOLID95 is selected as material type for meshing. As mentioned in the previous section, three springs are used for a model of a pin and COMBIN14 is selected as spring model. Real constants of the spring will be varying for every pin respect to workpiece geometry. Value of Real constants is pin stiffness for axial and tangential direction. Slip is evaluated by comparing pin radial deflection and workpiece node radial deformation.

Workpiece geometry is modeled using Catia software and imported to Ansys and meshed using VSEL command. For PSO Evaluation, the selected area where the pins are contacted is further refined using “NREFINE” command. Pin is located to the node which is closest to actual pin position. Obtaining the closet not is performed using NODE(PUX(J),PUY(J),PUZ(J)) command. PUX,PUY and PUZ are actual pin coordinate while J is pin index. Following script is codes for refining mesh at pin locations.

```
!left side pins
*DO,J,1,JPIN/2
```

```
        *if,CPU(J),EQ,1,THEN
                NUPIN = NODE(PUX(J),PUY(J),PUZ(J))
                NREFINE,NUPIN, , ,1,1,1,1
        *endif
*ENDDO

!right side pins
*DO,J,1,JPIN/2
        *if,CPL(J),EQ,1,THEN
                NLPIN = NODE(PLX(J),PLY(J),PLZ(J))
                NREFINE,NLPIN, , ,1,1,1,1
        *endif
*ENDDO
```

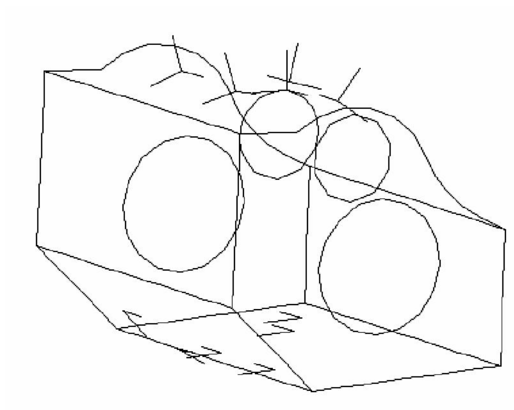

FIGURE 3: Pin-Workpiece Contact model

Fig. 3 shows a spring orientation for clamped workpiece. Support for upper side has three springs while lower side by two vectors. One another vector for lower side is hydraulic clamping with direction always parallel to pin axial axis.

7. HYBRID EVALUATION USING PSO ALGORITHM

Genetic algorithms have no mechanisms for identification absolutely the best solution of particular problem. However, a solution is "better" only in comparison to other, presently known solutions. Algorithm to obtain an optimal solution has to be tested with another way to check whether a solution is optimal. Hybrid technique is second optimization step that runs after the genetic algorithm terminates in order to improve the value of the fitness function. The hybrid function uses the final point from the genetic algorithm as its initial point. A hybrid function can be specified to improve the result.

In order to obtain better clamping position, hybrid evaluation is utilized by combining GAs with PSO algorithm. The PSO algorithm is utilized to determine the best position of the workpiece by shifting around y and z position. Particle Swarm Optimization (PSO) is a population based stochastic optimization technique inspired by social behavior of bird flocking or fish schooling.

PSO is initialized with a group of random particles (solutions) and then searches for optima by updating generations[15]. In every iteration, each particle is updated by following two "best" values.
After finding the two best values, the particle updates its velocity and positions with following equations.

v[] = v[] + c1 * rand() * (pbest[] - present[]) +
c2 * rand() * (gbest[] - present[]) (7)

present[] = present[] + v[] (8)

v[] is the particle velocity, present[] is the current particle (solution). pbest[] and gbest[] are defined as stated before. rand () is a random number.

There are two variables are used for evaluation using PSO algorithm. Two variables for the pin left and right side was used for GAs and another two variables, that are workpiece position in y and z is utilized for PSO evaluation. Pins configuration for left and right side it has been determined by GA to obtain the best configuration is further evaluated using PSO algorithm to obtain optimum positions of workpiece around the best configurations.

In order to reduce the time of calculation, larger mesh size is selected for GAs evaluation and refined mesh at clamping pin position is performed for PSO. The best position from range between -5.0 to 5.0 in y and z position is searched. Amount of movement is determined by PSO rules. Pins position and contact vectors are recalculated for new location of workpiece. Calculation is performed by sending a message to CAD software using Dynamic Data Exchange (DDE) interface function.

Twenty numbers of iterations and ten population sizes has been used with 0.9 initial inertia weight and 0.4 for final inertia weight.

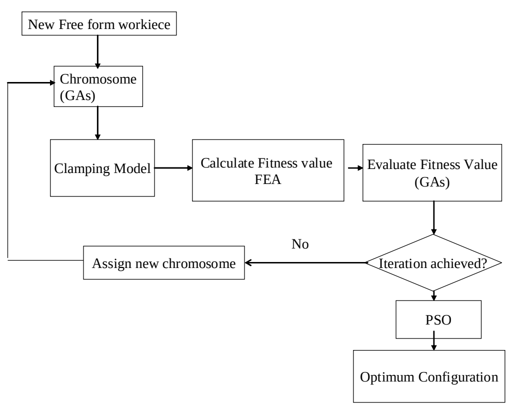

FIGURE 4: Hybrid evaluation scenario

Fig. 4 shows the overall procedure of optimization process with sequence explained as follows. New free form geometry is modeled using a CAD software. Initial configuration is assigned through a random number. Number is then converted to a binary value represent pin configuration. Clamping model for FEA process is generated respect to pin configuration model. Configuration model is evaluated using FEA software to obtain fitness value. Fitness value is then evaluated by GA rule for next generation of configuration with iteration process. Finally PSO is used for fine tuning the result obtained form GAs evaluation.

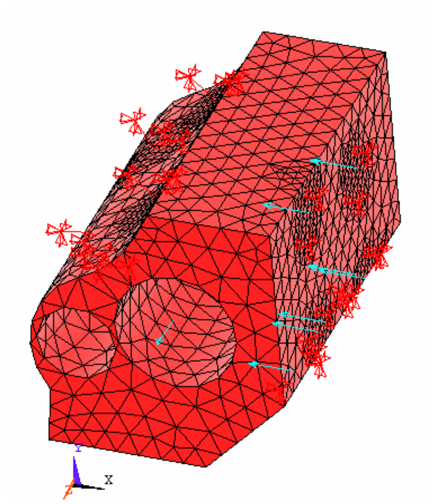

FIGURE 5: Sample workpiece evaluated using FEA for final clamp configuration

8. CASE STUDY

A prismatic 3D part model is used with geometry as shown in Fig. 5 and material properties as listed in Table 2. Cutting force is applied using three forces in x, y and z directions. There are eight pins in each side is applied to the model. Result of FEA computation written using *GET and *VWRITE command is further evaluated using functions created and executed inside Matlab for finding optimum clamping configuration using GAs and PSO. The material properties of the workpiece and pin elements are given in Table 1.

Table 1 Table Material Properties used for FEA

	Workpiece	Pin element
Material	Alloy Steel	Tool Steel
Young's modulus (GPa)	206	217
Shear modulus (GPa)	73	73
Poisson's ratio	0.3	0.3
Static friction coefficient	0.35	

The evaluation source codes are created using Matlab and interfaced with Ansys for calculation the objective function. First process is assigning initial parameters such as number of iteration, population size and generating meshed workpiece model with no supporting and clamping pin. Meshed workpiece is used to obtain the node number for contacted pins. Second process is generating pin workpiece model with configuration as defined by chromosome codes. Spring constant for used pins in radial (Kr) and axial (Ka) are calculated and the result is stored in pin-workpiece model data. The next process is evaluation the clamping model using FEA to obtain maximum deformation and deformation at pin contacted nodes. Deformation data is used to calculate friction slip and fitness value. Slip in pin contacted nodes is occurring when workpiece tangential deformation is more that pin deformation due to friction force. Configuration is categorized as violation if slip in any contacted pin is observed. The evaluation process is repeated until reach the assigned number of populations and generations.

Optimum configuration obtained from GAs evaluation is then evaluated using PSO to obtain minimum workpiece deformation by shifting the workpiece position. PSO will search the optimum position with the configuration obtained by GAs. Workpiece location in x and z direction are dimension parameters adjusted during iteration processes of PSO evaluation. Random number is generated in the range of pin distance in x and z direction.

The magnitude of 500N clamping force is used for every pin. Cutting force is applied at right surface. Parameter uses during GAs evaluation is listed in Table 2.

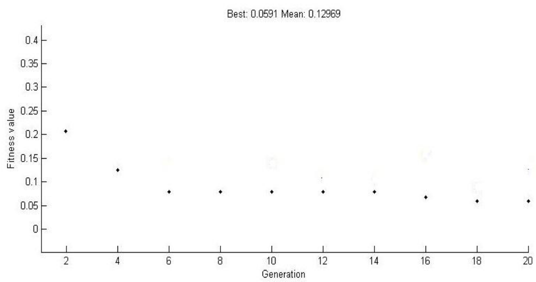

FIGURE 6: Result of Genetic Algorithm for 20 generations

TABLE 2. GAs Parameters

Parameter	Value
Population Size	10
Generations	20
Migration Fraction	0.39796
Crossover Function	1.1316
Mutation Function	0.2907

Result of GAs evaluation with complete iteration is given in Fig. 6. Optimum configuration after 20 generations is 0.0591 with pin configuration chromosome 0000001100101110 and 0000111011001100 for left and right side respectively. Actual pin configuration converting from the chromosome code is shown in the Fig. 5 which have 6 pins for supporting and 7 pins as clamping.

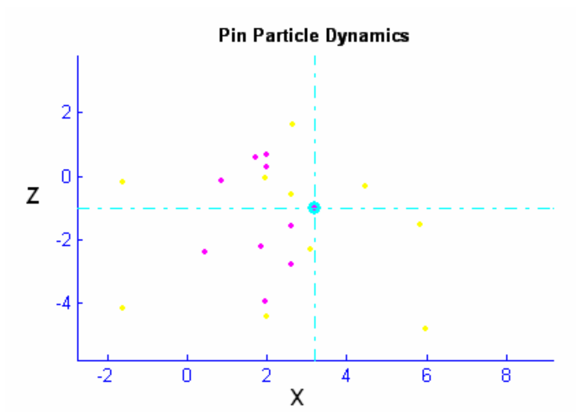

Fig. 7: Dynamics of workpiece Positions during PSO evaluation.

The hybrid function uses the final point from the genetic algorithm as its initial point. A hybrid algorithm is used to improve the result. The second algorithms using PSO are performed to determine the best position of the workpiece. The area between -5.0 to 5.0 in y and z position is searched by dynamically move the workpiece. Value 5.0 mm is the half distance between two closest pins. Process of iteration using PSO rule is shown in Fig. 7. Result after evaluation was shift the workpiece position by 1.3950 and -0.7576 in y and z direction respectively with fitness 0.0541. PSO optimization was moving the workpiece to new location with the less amount of clamping deformation.

9. CONCLUSION

Spherical type pin fixture has been considered as suitable tools to hold a free from workpiece geometry. Evaluation of clamping ability has been performed through Finite Element Analysis for computation of workpiece deformation and detection of slip. Three springs for representing a pin contact vectors possible to reduce the calculation time during iteration process.

Optimization of pin configuration and position for pin type fixture was enabling to minimize workpiece deformation during clamping. The simulation model developed using Genetic Algorithms and PSO algorithms integrated with Finite element method enable to obtain the better configuration of pin respect to minimum deformation.

Optimization technique was performed using hybrid algorithms, GAs and PSO, with four input parameters. Result of optimization process enables to obtain the better pin configurations and clamping positions.

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NOMENCLATURE

c1 First learning factors of PSO algorithm.
c2 Second learning factors of PSO algorithm.
δ_z spherical clamping static deformation at axial direction
δ_j spherical clamping static deformation at radial direction
$\delta 2_r$ pin static deformation at radial direction
$\delta 2_j$ pin static deformation at tangential direction
E elastic modulus
F_a axial reaction force at *j*th pin
G Shear modulus
v Poisson’s ratio
K_z pin stiffness at axial direction
K_{bt} radial stiffness of cantilever bream fixed at one end
K_{pt} spherical pin stiffness for tangential direction
L Pin length, distant from host to contact surface
P clamping force
Q tangential contact forces of pin.
R Pin radius
μ Static friction coefficient