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Pin type Clamping Attachment for Remote Setup of Machining Process

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***Abstract*—**Sharing the manufacturing facility through remote operation and monitoring of a machining process is challenge for effective use the production facility. Several automation tools in term of hardware and software are necessary for successfully remote operation of a machine. This paper presents a prototype of workpiece holding attachment for remote operation of milling process by self configuration the workpiece setup. The prototype is designed with mechanism to reorient the work surface into machining spindle direction with high positioning accuracy. Variety of parts geometry is hold by attachment to perform single setup machining. Pin type with array pattern additionally clamps the workpiece surface from two opposite directions for increasing the machining rigidity. Optimum pins configuration for conforming the workpiece geometry with minimum deformation is determined through hybrid algorithms, Genetic Algorithms (GA) and Particle Swarm Optimization (PSO). Prototype with intelligent optimization technique enables to hold several variety of workpiece geometry which is suitable for machining low of repetitive production in remote operation.

***Keywords*—**Optimization, Remote machining, Genetic Algorithms, Machining Fixture.

I. Introduction

ACCESSING the manufacturing facilities from remote is an efficient way for high responsive of production facility. Especially for a machining shop floors which are characterized with manufacturing the large variety of products with small batch repetition, a remote operation of a machine become necessary to reduce the overhead cost. The cost and lead time of new fixture design is taking a significant percentage in the overall production stage. Flexibility of the fixture for holding a variety of parts with different geometry is importance for reducing manufacturing cost.

A workpiece are should hold maintain within acceptable accuracy and stability during machining process. Every point of the clamping elements 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. New holding equipments have to be selected and arranged for machining new part design. Selection of many fixture elements and requirement for multiple setups is the main reason way a remote machining operation is unpractical.

Various activities utilizing the Internet communication for manufacturing systems have been also developed in the past decade for supporting life-cycle phases of product development. Many product development software tools, such as CAD systems, CAM systems, database management systems, knowledge-based intelligent systems, have also been integrated through web-based manufacturing [1]. Although many web-based manufacturing systems have been developed, most of these systems were implemented only for accessing the software and data. Importance and usefulness of Internet communication of manufacturing systems for improving product of manufacturing industry by directly access shop facility have not been demonstrated. The weak of holding attachments is one of the problems need to solve for performing the automatic setup. The effective remote manufacturing systems are reasonable when no manual setup have to be conducted at shop floor site.

In line with advanced technology of CNC machine with high accuracy machining, it is not necessary to perform finishing process using a grinding machine. A part could be machined in a machine tool with finish accuracy. However, fully automated operation is not being performed due to fixturing the workpiece. It is proposed to develop a single multipurpose machining attachment for variety products is solution for performing remote setup. Process plan of CAPP software arranges the number of setup to single process and selects installed machining attachment for holding. Manufacturability of a part could be evaluated effectively since only single attachment is considered.

II. Literature Review

A fully automatic system in term of hardware and software are necessary for remote machining. There are four systems have to be ready for performing a remote machining. Those systems including Internet communication for design collaborations and handling the data transfer, software for preparation the machining data and evaluation of manufacturability, workpiece holding attachment, and machine tool. Following are review of the system.

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Many new web-based tools have been developed for improving the functions of data modeling. Java applets, Virtual Reality Modeling Language (VRML), Java3D and XML are technologies capabilities of data modeling in developing Web-based manufacturing systems [1]. Many researches utilizing Internet tools for product data modeling have been also conducted [2] [3].

Evaluate the performance of the fixture-workpiece model through Finite Element Analysis (FEA) to determine the better configuration for workpiece setup has been demonstrated by several researchers. FEA was used as a platform for cost-effective and accurate simulation of complex dynamic fixture–workpiece behavior [4] [5] [6]. Calculation of deflections using FEA for the minimization of the workpiece deflection at selected points as the design criterion also introduced [7]. Commercialized FEA software, Ansys, is utilized to verify fixture design integrity and the optimization analysis [8].

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 [9][10][11].

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. Integration of the systems for performing an automatic machining is not demonstrated due to lack of equipment design. This paper proposes a new technology of workpiece holding attachment which can be used for remote machining using CNC milling machine. Mechanical hardware is presented at beginning of the paper followed by client server application software for monitoring and operation. Last part of this paper discusses the technique for obtaining the optimum clamping configuration.

III. Auto Setup Machining Attachment

Reconfigurable fixturing is becoming a necessary component in order to reduce the cost of fixture development. Setup free attachment with Pin type clamp is a solution for free form geometry where only single fixture for many workpiece design. Variety of parts geometry could be hold 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. A part hold by setup free attachment could be machined completely in one process by using long round bar as raw material.

An auto setup CNC milling machine which is equipped with specially developed Setup Free Attachment is investigated as one solution for remote machining process. A specially designed attachment with setup free machining methodology has been developed for horizontal machining center as shown in Fig. 1. By the attachment mounted on the table of a horizontal machining center, a small size component designed by specially developed CAD/CAM software can be automatically machined from all of the surfaces in single process without using other fixtures. Attachment consists of three main equipments; material indexing device, Sub clamp and vise index, for locating and orienting the workpiece.

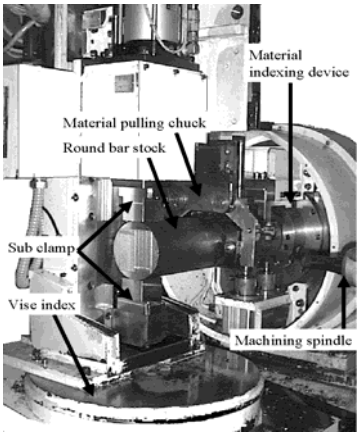
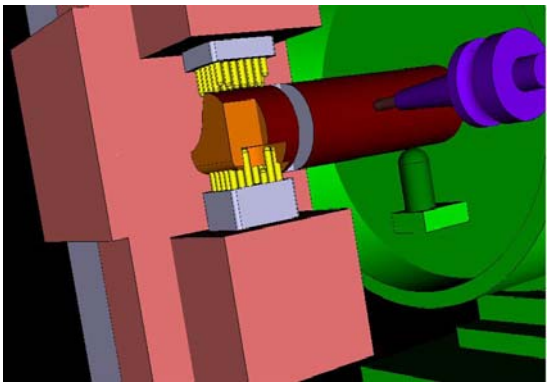
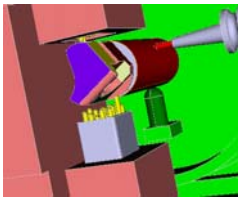


Fig. 1 Setup Free Block Machining Attachment

Function of the material rotating device is to hold the round bar material and rotated for machining from circumferential surfaces. Sub clamp which is have a pairs of reconfigurable pins is used to increase the rigidity on machining process and become a main clamping device after part is parted off from round bar material. A designed part is possible to be machine completely in one process for all surfaces without changing the setup.



(a)



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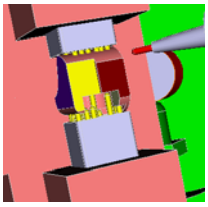

(c)

Fig. 2 Virtual Model of Pin Type Reconfigurable Setup Free Attachment

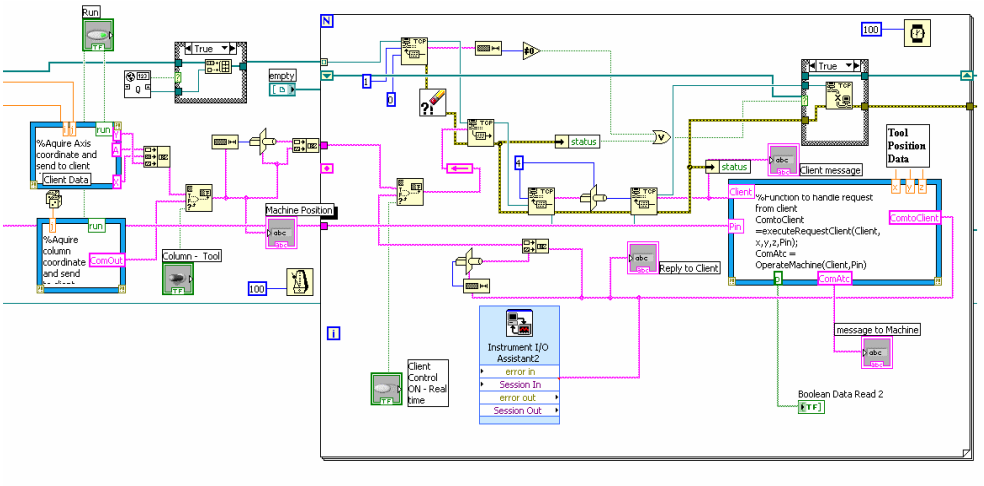

Fig. 3 Block diagram of Server Application

Pin-type reconfigurable fixture as shown in Fig. 2 is attached at sub clamp for clamping irregular surfaces. A pin type fixture consists of a main body or base that contains a two-dimensional array of orthogonal to the base roads or pins. Each pin is protruded downward independently, and therefore all the tips of the pins form a cradle conforming to the shape of the workpiece which is fixed during manufacturing operation. Pins are actuated independently using hydraulic pressure.

The attachment is suitable for machining low repetitive small size components. Machining process is started by machining from circumferential surfaces as illustrated in Fig.2 (a). Reorientation of the part is performing by rotating the Material indexing device (Fig. 2 (b)). After the part is parted off from round bar, sub clamp with pins is applied to holds the machined workpiece (Fig. 2 (c)). .

Remote monitoring of the system is conducted by developing a client-server application. Task of server is to receive data from client, responds the client message to update the representation of virtual model. Depending on type of operation requested by client, the movement command will be sent to attachment controller through PCI 6251 data acquisition.

Fig. 3 shows block diagram representation of server developed using Lab View. Communication between client and server is conducted efficiently by sending only position coordinates of attachment components through text string data format. Transferred data communication is monitored using control panel of server as shown in Fig. 4.

Visualization of the machining operation is presented using VRML format of 3D model as shown in Fig. 5. User from remote either monitoring the simplified machine activity can also conducted several operations such as opening and closing the clamp.

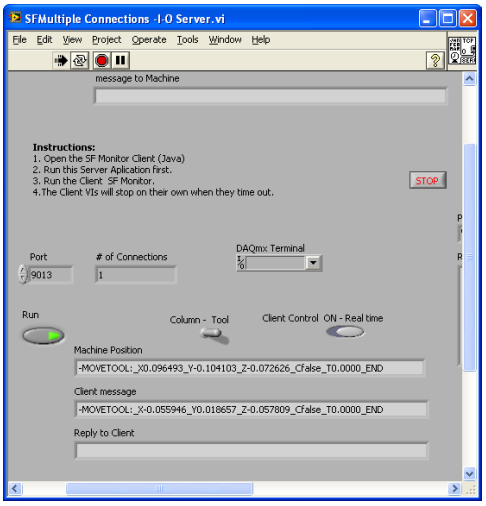

Fig. 4 Control panel of Server Application

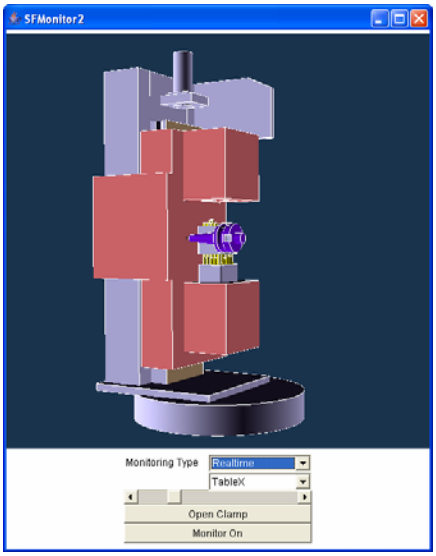

Fig. 5 Setup free attachment represented as client

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IV. GA and PSO Hybrid Clamping Optimization

The technique in simulation of pin configurations is to represent every point where the pins are in contact with the workpiece.

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 as the function of clamp in axial force and coefficient friction have to be calculated. Friction force should strong enough to prevent slip of the workpiece. However, increasing the friction force may affect to the part quality. Finite Element modeling is used for evaluation of deformation and slip. 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 for quick computation of iteration. Parametric script file is built for accepting a variety part model.

Determination of Pins configuration is initiated by selecting usable pins by interfere contact analysis. Result of this analysis is further continued to obtain the optimum configuration. Hybrid optimization, Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) is used to obtain global minimum. GA optimization is resulting optimum configuration while PSO is to determine the best position. Following are brief theory of GA and PSO.

Genetic Algorithms (GA) 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. GA 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 Particle Swarm Optimization (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.

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 GA 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]. Particle is updated for every iteration respect to two "best" values.

After finding the two best values, the particle updates its velocity and positions with following equations.

$$v[] = v[] + c1 * rand() * (pbest[] - present[]) + c2 * rand() * (gbest[] - present[]) \quad (1)$$

$$present[] = present[] + v[] \quad (2)$$

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 GA 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 GA 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.

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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.

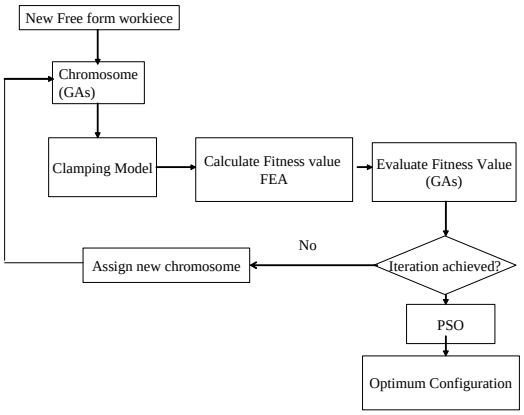

Fig. 6 Hybrid evaluation flow diagram

Fig. 6 shows the overall procedure of optimization process using GA and PSO. A new free form solid geometry is modeled using CAD software. Initial configuration is assigned by GA through generating a random number. A number is then converted to a corresponding binary value represent the pin configuration, number 1 is attached pin while 0 is detached pin. Clamping model for FEA process is generated respect to pin configuration model. A configuration model is evaluated using FEA software to obtain fitness value. Through iteration process, a fitness value is evaluated by GA rule for calculating the next configuration. Finally, PSO is used for fine tuning the result obtained from GA evaluation.

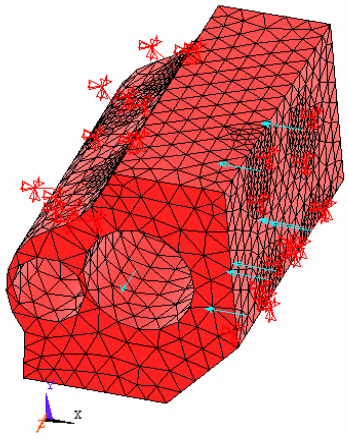

Fig. 7 Sample workpiece evaluated using FEA for final clamp configuration

Twenty numbers of iterations and ten population sizes has been used for a sample part as shown in Fig. 7. Result of optimization is shown in Fig. 8. Optimum configuration is chromosome 0000001100101110 and 0000111011001100 for left and right side respectively. Actual pin configuration converting from the chromosome code is shown in the Fig. 7 which has 6 pins for supporting and 7 pins as clamping. Maximum deformation as the result of Finite Element Analysis for this configuration is 0.0591 mm.

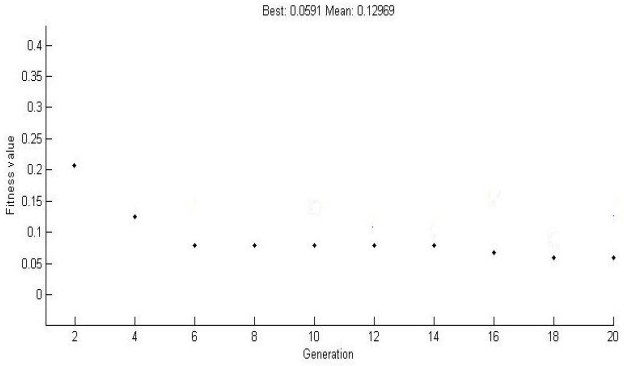

Fig. 8 Result of Genetic Algorithm for 20 generations

V. Conclusion

Setup Free attachment with pin type reconfiguration has been investigated as a tool for performing remote machining. Operation of the machine is monitored from client through virtual visualization. A workpiece is machined with a single process completely from all surfaces without necessary manual setup. Spherical type pin fixture is used to hold a free from workpiece geometry at final machining operation. Evaluation of clamping ability has been performed through Finite Element Analysis for determination of optimum pins configuration. 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 to obtain the best configuration are suitable for automatic workpiece setup.

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