Design and Development of Flexible Fixturing System for Handling Irregular Shaped Components

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Abstract—**Manufacturing industry is a rapid developing area and requires new technologies and concepts to increase the profit margin through high production rate and high quality. To have a sufficient and higher production rate there should be competent fixturing systems, because fixtures perform major tasks such as locating, holding and supporting components during manufacturing processes. Due to the large variety of the components manufactured in the industry, the fixture systems differ from one another. Therefore dedicated fixtures are widely used in the industry. Aerospace and automotive industries are facing problems such as huge space allocation for large number of dedicated fixtures, long lead time for designing and fabricating and low flexibility to change the setup at the modifications of the design. These problems cause to increase the overall cost and slow down the production. A reconfigurable or modular fixture can be introduced as a single fixture for set of components. Although it reduces the number of fixtures, leads to other issues such as high knowledge and skills required to change the setup and inadaptability with robot cells and flexible manufacturing systems because of human involvements. Flexible fixtures can be used to minimize the problems associated with irregular shaped components. This paper discusses proposed solutions of an ongoing project on flexible fixturing system for handling irregular shaped components. Alternative concepts introduced in the paper are flexible and reconfigurable. Therefore they can be applied to industries such as aerospace, automotive, stamping and ship building.**

Keywords—flexible fixturing systems; modular fixturing systems; dedicated fixturing systems

I. INTRODUCTION

The concept of fixturing systems goes to number of decades back. In early stages fixtures were originated with jigs at the Swiss watch industry. Those concepts were spread throughout the whole manufacturing industry after proving their usefulness to the industry [1]. Then basic fixture tools such as locking pliers and C clamps have been introduced. With the increasing of the accuracy and rigidity requirements, other basic fixturing methods such as bench vices and chucks came to the industry. Generally 10 % - 20 % from the total manufacturing costs is allocated for designing and fabricating fixtures [2]. Therefore to reduce manufacturing costs, fixture systems are designed as to handle number of components by using the same system. Likewise development of flexible fixturing systems help to reduce the unit cost of production.

Trappey and Liu have reviewed basic fixture design concepts [3]. According to that review work pieces can be categorized into prismatic parts, general parts with existing hole(s) and non-prismatic parts. Further there exists total of twelve linear and rotational movements relative to the three axes. Fixturing means restrict the all free movements of the component. Only few numbers of movements are restricted by the supporting and locating methods while remaining are restricted by the clamping methods. The 3-2-1 principal is the main supporting and locating principal used in existing fixturing methods [3, 4, 5, 6].

Production line concept was developed with the batch product manufacturing and with the increasing of repeating products. In the production line concept, idling time of machines is directly affected for production rate and thus manufacturing cost [7]. Dedicated fixtures were introduced as a solution for that problem. These fixtures may effective if the industry produces only few types of components with a high production rate for a long time period, because once the fixture is fixed it is very hard and expensive to remove or change the location [8].

An et al. proposed an automated dedicated fixture configuration design that can be applied to predefined component types in mass production [9]. This dedicated fixture is made up with several functional units on a fixture base to full fill the certain fixturing functions including locating and clamping. The main issues of these dedicated fixtures are costly and highly time consuming for designing and fabricating. Due to these issues researches were carried out to design an advanced fixturing system. Modular fixturing and inter-changeability concepts were introduced as a result of that problem at the time of Second World War [10]. Those systems first came to the industry in 1960s with the usage of NC machines.

Zheng and Qian introduce a systematic study of 3-D modular fixtures, particularly for complex objects [11]. This modular fixturing method includes equilaterally arranged three base plates and total of seven fixels on those base plates. Two base plates and all fixeles can adjust automatically for a work piece according to an efficient algorithm they developed.

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Zhang et al. have developed a modular mechanism system to weld sheet metal components in automotive industry with platform, independent host locating mechanism and supporting columns based on the requirements of better rigidity, higher accuracy, better machining technological efficiency and shorter assemble time of reconfigurable welding assembly fixtures [12]. This system consists with locating pins and clamps which can be adjusted in three directions.

Sela et al. have developed fixturing systems for thin-walled flexible objects such as turbine blades [13]. These systems consisted of two suction clamps and pneumatic plungers. Then a design was introduced to the industry which has multipoint contact with the work piece, lockable spring loaded plungers and changing properties to achieve conformability to odd shaped work pieces [14, 15]. Aoyama and Kakinuma developed a fixture for thin walled work pieces that can support thin parts securely and with less deformation using multi-pin supporter system with low melting alloy as the working fluid to assist the work piece [16].

Yu et al. have introduced a reconfigurable fixturing robot for sheet metal assembly [17]. The robot consists with parallel manipulators to change the locating point over a required space. Ryll et al. introduced an intelligent fixturing system having rapid reconfiguring and past positioning ability [18]. This fixturing system is based on the modular fixturing equipments, movable actuators and sensors. Modular fixtures are transport to the suitable positions on the rails mounted on the platform according a virtual fixture design.

Reconfigurable systems also have issues such as requiring more technical knowledge to determine modular fixture configuration, availability of limited combinations and difficulties in maintaining structural properties. Therefore there was a need to have flexibility in fixturing systems. Colbert et al. have proposed a flexible design for machining of prismatic work pieces which consists of a base plate, various tool point units and clamps with built-in micro switches [19]. Toumi et al. were introduced a flexible fixturing system to drill sheet metal parts [20].

Arzanpour et al. have developed a fixturing system to fulfil the objective of grasping a number of sheet metal parts, one at a time and to assemble those parts in a robotic assembly cell using suction cup technology [21]. Leonardo et al. designed locomotion and docking system for machining complex shaped sheet metal components using parallel manipulators and new reliable swing motion to reach the robot to required position [22]. Zielinski et al. developed that system into a multi robot based reconfigurable fixturing system [23]. Once again Kasprazak et al. developed this reconfigurable fixturing system including task planning to guarantee a stable support for the work piece [24]. New design uses a phase changing magneto rheological fluid to ensure the self adaptability of the supporting head for the complex shape. Hong and Grier developed a three fingered automated flexible fixturing system which can handle planer objects in machining processes [25].

Monkman has proposed a solution combining electro-adhesion and electro-rheological fluids that can be used as force inducing media for irregular shaped components [26]. A new universal fixturing method called reference free part encapsulation has been presented by Sanjay and Paul [27]. Low melting point molten alloy pour into a mould with partially submerged work piece. The mould creates a common shape that can be mounted on a common fixture.

Although there are number of fixturing systems in the field, they have many issues. Industries like aircraft and automobile maintain large number of dedicated fixtures due to the variations of components they produced and it leads to huge space allocation. The cost and lead time for design, fabrication and modifications are also higher for such fixtures. Higher skill requirement to operate and setup the reconfigurable fixture is another problem. Majority of flexible fixturing systems identified in the literature associated with less accuracy and less rigidity. These issues can be reduced by using effective flexible fixturing methods. This type of flexible fixtures should have ability to handle irregular shaped and various types of components accurately and rigidly.

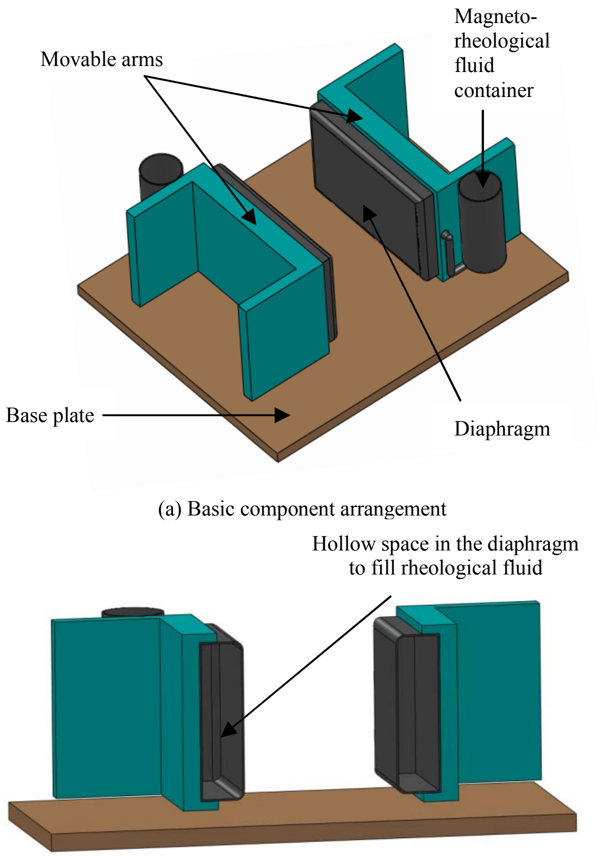
Currently there are so many researches carried out regarding fixturing systems, but those designed and proposed solutions have varying degree of success. Next section of the paper describes proposed alternative concepts for flexible fixtures providing solutions to the identified issues.

II. System Implementation

A. *Concept Model 1*

The system additionally consists with rubber diaphragm covering the magneto-rheological fluid and cylinder, piston couple to contain and control the fluid. Other forcing mechanisms are as in conventional methods such as screw mechanism or pneumatics cylinder method. The arrangement of this system is shown in Fig. 1.

Initially the fluid pressure inside the diaphragms keeps in atmospheric pressure. After placing the component between two diaphragms they force to move till the component gets considerable contact with the diaphragms. The movement controls according to the fluid pressure inside the diaphragm. Then the magneto-rheological fluid inside the cylinder forced into the diaphragm. This causes to the diaphragms to get the passive shape of the component. After reaching the fluid pressure certain level, inserting the fluid is stopped. After applying a magnetic field backside of the diaphragm by means of electric magnet, the fluid get phase change from liquid to solid. Now these two diaphragms act as dedicated fixture for placed component. Then the direct force can apply for the component. Because of uniform contact between the component and diaphragm, the force applied is uniformly



(a) Basic component arrangement

(b) Cross section

Fig. 1. Arrangement of Concept model 1

distributed throughout the contacting area of the component. Therefore a rigid contact can be secured while machine operations perform on the component.

Removing the component can be done by releasing the direct force, disconnecting the magnetic field and moving the diaphragms away the component. The fixturing can be done for completely different components in the same way by this fixturing system. Uniform force introduction to the component is a huge advantage and it leads to minimize the localised deformation of the irregular shaped component.

B. Concept Model 2

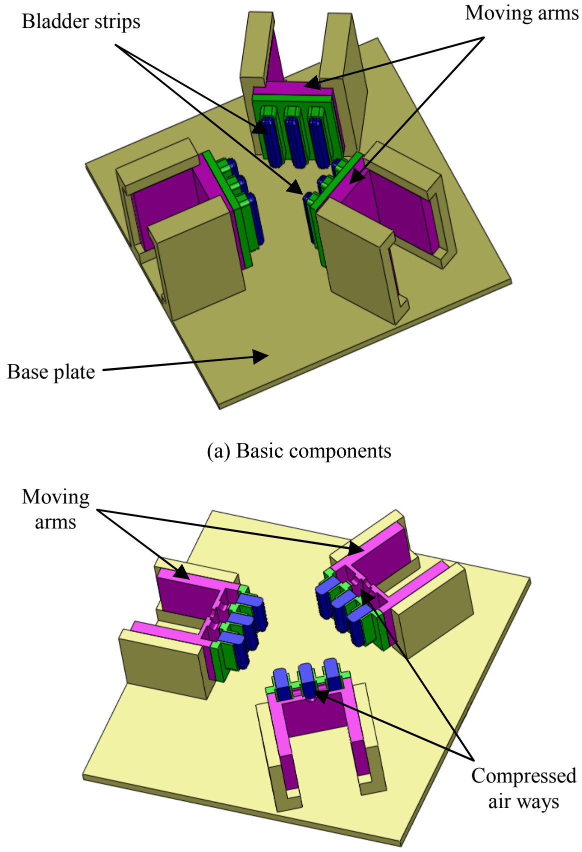
The component is directly forced by two bladder clamps in conventional designs. Rubber with considerably high rigidity is used to prevent the movements and vibrations of the component after clamping. In this concept bladder can deform only within a small range of distances because of relatively high rigidity. New design consists of three moving arms and nine strips of bladders. Number of strips in the design can be increased according to the requirement. Important parts of the conceptual design are shown in the Fig. 2.

Irregular shaped component is placed on the middle of the system. Then three arms move while at least one bladder touches or very close to the object surface. Detecting the closeness is done by proximity sensors. Then compressed air pump into the cavity of the arms and it pushes the bladder strips to the surface of the object. Compressed air flow is controlled to minimize the deformation of the object. After the pressure inside the cavity come to a certain level, the air supply close and hold. Then the three arms can simultaneously force to the object to have the required rigidity. Arm moving can be done pneumatically or mechanical ways such as screw mechanisms as in conventional vices. Flexibility is achieved by small deformation of the bladder strips in vertical direction and arrangement of the nine bladder strips. The design can apply for 3D objects having high irregularity on horizontal planes and low variety in vertical direction such as objects with bottle shape.

C. Concept Model 3

The design consists of twelve screw pins and individual geared motors to drive the pins. Number of pins can be increased according to the application. There is an automated surface detection method included in each pin. Fig. 3 shows the basic arrangement of the screw pin fixture design.

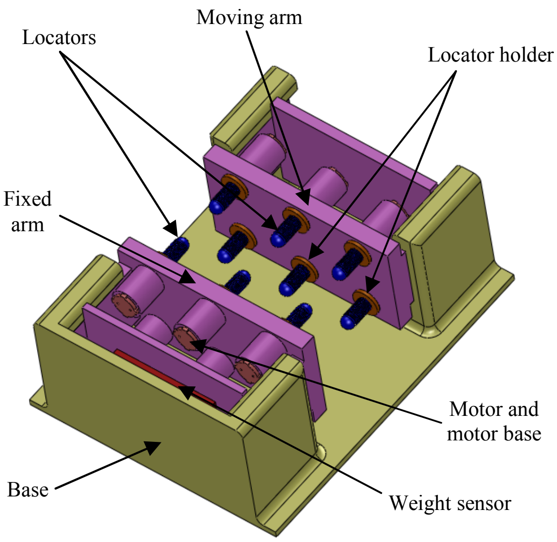
Motor base is free to move in a grove on the arm. Locator pin with locator holder can be simply attached to the arm as



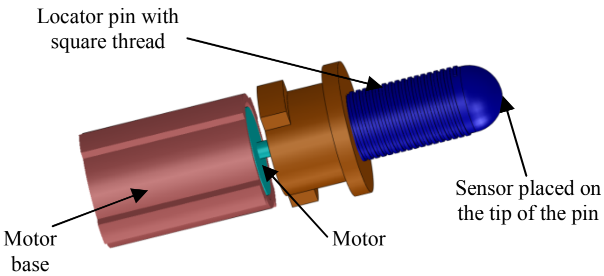
(a) Basic components

(b) Cross section view

Fig. 2. Arrangement of Concept model 2



(a) Basic components



(b) Locator pin and motor assembly

Fig. 3. Arrangement of Concept model 3

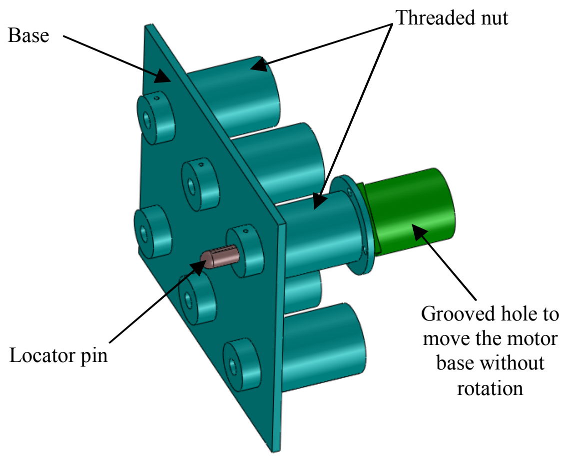
the pin connects with the motor shaft. While rotating the motor, the pin extends by rotating through the locator holder by means of thread. The motor base moves in the same direction without rotating. A microcontroller is used to program the system. Weight sensor is located at the back of the fixed arm to measure the force applied on the object.

Initially all the pins are in folded position. After positioning the object at the allocated place of the fixture, the moving arm move forward till at least one pin contacts the surface of the object. The contact can be detected by the force sensors located at the tip of the locator pins. Then moving of the arm is stopped and locator pins individually extend to the object by means of motors till all of them are touch with the object. Then the moving arm can be forced to certain level to complete the fixturing. Weight sensor used to measure the force and control the forcing to pre defined value. The fixture can be applied for thin objects as well as the thick 3D objects.

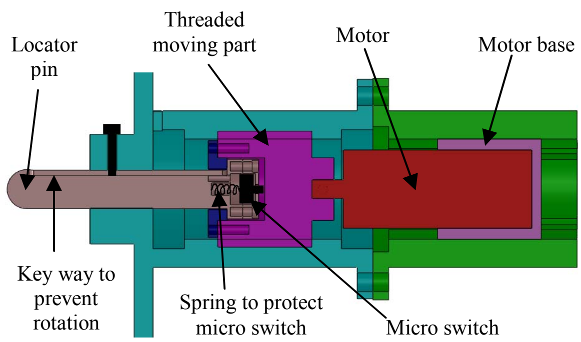
Fig. 4 shows advanced locator pin concept solving direct problems associated with above mentioned concept. It solves the problem of twisting connecting wires of force sensors located at the tip of the pin. New concept consists of micro switches. The locator pins do not rotate with the motor and it only move forward and backward without rotation. Force sensor can be damaged at high force because it compresses between component and pin. New design gives protection to the micro switch at high load by introducing a spring. Other functions and controlling sequence is same as mentioned in earlier. Fig. 5 shows the controlling sequence in a block diagram.

The threaded moving part goes forward and backward through the threaded nut while motor rotates clockwise and anticlockwise direction. At the same time locator pin with key way go forward and backward without rotating. If the locator pin contacts a surface of the object the micro switch tend to compress and it change the state at pre calibrated force limit. This signal can be taken as the surface detecting signal. The spring placed inside the locator pin protects the micro switch against high forces. Shape of the pin can be changed according to the application.

Since micro switches use as surface detection sensors the operating forces of the micro switches are important characters of the system. The expanding of the locator pin will stop when the force exerted on it equals to the force needed to switch on the micro switch and it will fold again after the force come to the switching off value of the micro switch.



(a) Overall view of one arm



(b) Cross section of a pin and motor assembly

Fig. 4. Advanced mechanism for locator pin fixture

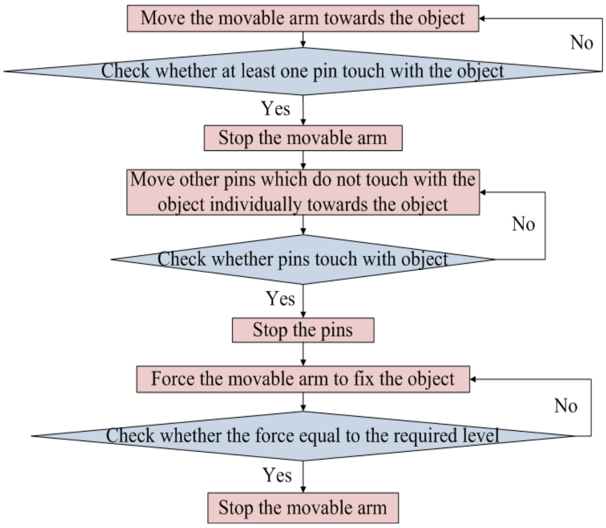
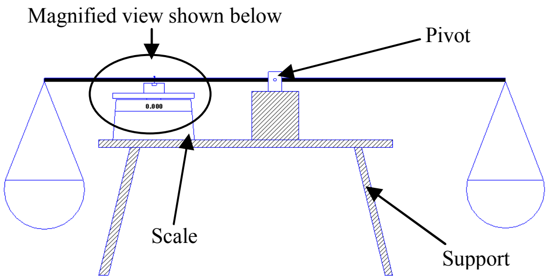


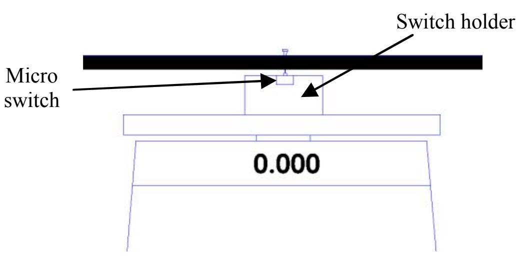
Fig. 5. Flow diagram of the operation

Fig. 6 shows the basic setup for measuring the operating forces of the micro switches. Switching ON force and switching OFF force were measured for four randomly chosen micro switches.

Micro switch has connected with LED to identify the state change of the switch. Applying and releasing force on the micro switch were done by adding fine sand into the cups. Mean values of measured operating forces for switch ON and switch OFF are shown in Table 1. According to the measured results it was concluded that the switch comes to ON state within the range of 250g – 270g and it comes to OFF state within the range of 45g – 55g. Therefore one locator pin required maximum of 270g to detect the object surface and object should have capacity to withstand that force.



(a) Basic setup



(b) Magnified view of micro switch, holder and scale

Fig. 6. Experiment setup for micro switch

TABLE I. EXTRACTED RESULTS FROM THE EXPERIMENT

Switch No.	***1***	***2***	***3***	***4***
Force required to switch ON (g)	266.68	265.22	250.31	262.90
Force exist when switch OFF (g)	49.60	49.43	51.30	43.62

III. CONCLUSIONS

Selection of the fixturing method is varying with the parameters like shape, size and material of the components to be manufactured. Currently large numbers of dedicated fixtures are used in industries like aerospace and automobile, because of huge variations in the components. Using a flexible fixturing system for more components is a feasible solution for this issue. There are so many researches carried out related to this field. Those designed and proposed solutions have varying degree of success. Most of the solutions cannot be practically usable, because of the less rigidity and less space allocated for machining operations. Almost all the designs do not have an ability to deal with irregular shaped components. Therefore the main objective of this project is to design a reconfigurable and flexible fixturing system to handle irregular shaped components. After conducting a thorough study, drawbacks of the existing systems were identified and implemented new concepts to have a proper flexible fixturing system.

First concept model is theoretically very accurate because of the way of contacting the component surface with the fixture. Surfaces of the fixture and component fully contact with each other. But practically available magneto-rheological fluids do not change from liquid phase to fully solid phase with the application of magnetic force. Therefore required rigidity cannot be easily achieved for applications such as machining. But the concept can be used as a material handling method. Second concept is based on rubber bladders and pneumatic system. Limited extension length of bladder strips is one drawback of this model. Therefore components with high waviness cannot be accurately fixed with the system. Third concept has solid contacts with the component. Therefore a rigid fixturing can be achieved. Introducing a controlling system is much easier for this model. Pin extension length easily can be increased by modifying the design. By increasing the number of pins and introducing extra features from first and second models, accurate and widely applicable flexible fixturing system can be developed.

Experiments have been carried out to obtain exact data for the designs. Further information and detailed final design will be introduced with system validation results in our next publication.

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