Development of a reconfigurable fixture for low weight machining operations

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Abstract: Fixtures are production tools used to accurately manufacture duplicate and interchangeable parts. They are specially designed so that large numbers of components can be machined or assembled identically and to ensure interchangeability of components. It eliminates problems of marking out, repetitive check or work setup, measuring and other setup before machining. In this study, a reconfigurable fixture was developed using pneumatic controllers. The materials employed for this study include: a surface plate, six double-acting cylinder, two movable frames, four 5/2-way double solenoid valves, two side brazes, four 1-way flow control valves and three manually operated switches. The design was carried out with the aid of Autodesk Inventor and simulation of the developed fixture was done using FESTO fluid SIM to test the performance of the designed circuit and pneumatic cylinders. The result obtained from the finite element analysis indicates that the clamping force is enough to withstand operational and loading forces on the workpiece because the maximum stress induced on the fixture is lower than the yield strength of the material. Hence, the fixture possesses satisfactory rigidity and strength for clamping purposes. The successful completion of this work solves the...
problem of flexibility in holding low weight workpiece during mass production, thereby increasing productivity and accuracy.

Subjects: Industrial Engineering & Manufacturing; Mechanical Engineering; Manufacturing Engineering

Keywords: Fixtures; pneumatic; double-acting cylinder; work piece; yield strength

1. Introduction
Fixtures are production tools that are used for hold and locate workpiece during manufacturing operations (Taufik, Hirmanto, Sivarao, & Tajul, 2012). Conventional fixtures are not flexible enough to permit sufficient adjustment of workpiece during machining operations. The rigidity of the conventional fixtures often reduces the accuracy of surface finish while increasing production time and cost, hence the need for reconfiguration to enhance quick, automatic location and adjustment of workpiece with high flexibility, greater accuracy, and interchangeability. This will bring about high productivity, consistent clamping force and repeatable clamp location with attendant reduction in the production cycle time and cost. A reconfigurable pneumatically controlled fixture is designed to locate workpiece using four pneumatic cylinders inclined at an angle 45° to the horizontal that is moved by two pneumatic cylinders. The function of the four pneumatic cylinders and two movable frames of pneumatic cylinder is to adjust (increase or reduce) the workspace of the reconfigured fixture assembly. It will be an improvement over existing ones in that it will be controlled by six adjustable pneumatic double-acting cylinders with delay timers and magnetic cushion that will serve as an internal braking system to allow for smooth clamping. The magnetic cushion will be regulated with the aid of a screw adjuster attached to it. This will bring about a high degree of automation during adjustment of the workpiece as existing ones are limited to the use of manual and hydraulics that are not flexible enough. Furthermore, proximity switches incorporated will aid the forward and backward stroke of the developed system. The developed fixture is thus characterized with dynamic clamping forces and real-time location and control. These novelties will facilitate effective holding and location of the workpiece during machining operations. In addition, the finite element analysis of the developed fixture was carried out in order to determine the effect of machining forces during operations. Hence, the stress analysis of the reconfigured assembly fixture was done using the solid works simulation, to ensure that the clamp, locator, and supports of the fixture will not fail during operation.

1.1. State of the art
In recent years, there has been an effort to reconfigure existing rigid fixtures to more flexible ones. With the advent of CNC machining technology and the capability of multi-axis machines to perform several operations and reduce the number of setups, the fixture design task has been simplified in terms of the number of fixtures which would need to be designed. However, there is a need to address the faster response and shorter lead-time required in designing and constructing new fixtures. The rapid development and application of Flexible Manufacturing System (FMS) has added to the requirement for more flexible and cost-effective fixtures. Conventional fixtures which have been used for many years are not able to meet the requirements of modern manufacturing due to the lack of the required flexibility and low reusability (Figure 1).

From Figure 1, some of the challenges of the conventional clamping system include; excessive or inadequate clamping force, poor positioning and misalignment which affects the degree of machining accuracy, surface finish and product quality, increase in setup as well as loading and unloading time as well as lack of the required flexibility to permit frequent changes most especially machining involving mass production or complex geometries and orientation hence the need for reconfiguration to address the aforementioned shortcomings. The replacement of conventional fixtures by modular and flexible fixtures is eminent in automated manufacturing systems, due to much smaller batch sizes and shortened time-to-market requirement. Modular fixtures are constructed from standard fixturing elements such as base-plates, locators, supports, clamps, etc.
These elements can be assembled together without the need of additional machining operations and are designed for reuse after disassembly (Dongre, Gulhane, & Kuttarmare, 2014; Zhang, Zheng, Chen, & Huang, 2016). The main advantages of using modular fixtures are their flexibility and the reduction of time and cost required for the intended manufacturing operations. According to Zhongyi and Maropoulos (2014) as well as Navya and Pradeep (2013), automation in fixture design is largely based on the concept of modular fixtures. There is a need to reconfigure existing ones for efficient work holding capacity in order to increase the overall productivity. The main criteria for fixtures selection are based on three interdependent factors; costs, constructive details, and operation. In addition to these criteria, many characteristics must be analyzed, involving the part to be fastened, the manufacturing process, the machine tool and the fixtures themselves (Ulah et al., 2014; Zheng & Wang, 2013). Considering the benefits of modularity, particularly the aspects of flexibility and component interchangeability, Papastathis (2010) developed a reconfigurable fixture for the automated assembly and disassembly of high-pressure rotors for rolls-royce aero engines. The system consists of flexible modules with simple mechanism of support and location for each module. In addition, Zuperl et al. (2012) designed a concept for the development of a fixture, which incorporates intelligent elements. The work provided a design concept for automatic holding of thin-walled workpiece for machining operations while considering the effect of frictional forces for verification, rationalization and improvement of the clamping design. Also, Uday and Majid (2013), developed an integrated approach to assembly and automating modular fixture design. This methodology is comprehensive, involving dedicated fixture classification tasks, the development of rules for modularized component assembly and modular fixation component design. Considering the analysis of machining, clamping force, stability and flexibility, Yajie, Jinxing, Yilong, and Hengcan (2018), Zhizhen, Fangkai, Yikun, Shaofai, and Fuwei (2017) and Chun, Yunpeng, Hongrui, and Jiaoti (2017) designed special fixture for machining operations. The simulation of the designed fixture was carried out in order to determine the optimum clamping force. Wenbo, Xinkai, Chenggong, and Tenghui (2018) also designed a pneumatic fixture based on automotive sheet metal parts. It has the characteristics of precise positioning, gentle and simple clamping movement, which can significantly improve product quality and production efficiency while reducing the labor intensity of the users. According to Borjesson (2010), common modules can be standardized and produced in large batches, increasing the efficiency and quality of production and reducing costs, in addition to contributing to the company’s overall standardization. The increased modularity of a product produces positive effects on the total flow of information and materials, from its development and purchase to its stocking and delivery. Borjesson (2010) and (Borjesson, 2012) listed the following potential benefits of modularity: scale economy; greater viability of product/component exchange; increased product variety; reduction of lead-times, fragmentation of risks; easier diagnosis, maintenance and repairs, and greater product availability. The result was a variety of models based on computational programs with varying levels of automation, ranging from specialized systems based on different functional principles to sophisticated software programs for structural analyses as also reported by Arzanpour (2006), Mpofu and Tlale (2012) and Kumar, Yadav, Liou, and Balakrishnan (2013).

According to Simons (2006) and Goubert (2013), a press brake is a machine used to bend sheet metal in which a bottom tool is mounted on a lower stationary beam and a top tool is mounted on a moving upper beam. The primary characteristic parameters for press brakes are the tonnage,
working length, distance to the back gauge, working height and stroke (Goubert 2013; Suchy, 2006). In order to increase the efficiency of using a press brake for bending, many reconfigurations of its assembly fixture has been reported. For instance, Guimaraes, Pacheco, Meireles, and Fonseca (2009) introduced the use of standard robots while Gwangwava et al. (2014) designed a modular approach for the reconfiguration. Willa (2011), introduced the use of tool changer in addition to robot development for the fixture assembly while Olayinka, Mpofu, and Olga (2016) used hydraulic cylinders for the reconfiguration of the assembly fixture for press brake, taking into consideration the mechanical design and stress analysis of the component part of the fixture as well as the hydraulic system.

The aim of this work is to develop a reconfigurable fixture with pneumatic controls for positioning work for accurate operations while the objectives are to; design a reconfigured fixture using pneumatic controls, fabricate the designed fixture and carry out performance as well as the stress analysis of the fixture. The target is to explore the merits of pneumatic cylinders such as speed, effective control, reliability and precision to reduce cost, increase flexibility, productivity, and accuracy during clamping operations of low weight workpiece.

The work introduces the use of pneumatic cylinders for the development of a fixture limited to holding low weight components during machining operations. This is to enhance adjustable control and smart location of the workpiece for flexibility and interchangeability in order to reduce the setup or loading time through manual adjustment of the clamping force during machining. During machining operations, the changes in workpiece dimension, orientation as well as reaction forces requires control system to be responsive and automatically adjust, without intermittently halting the process. This will reduce the total machining cycle time and ensure accuracy as well as precision with a high degree of automation. In addition, the determination of the optimum clamping force will promote good surface finish. When the clamping force is below the optimum, there is a tendency for accidental fall or poor engagement of workpiece and tool at the interface thus increasing the machining time and surface roughness. On the other hand, when the optimum clamping force is exceeded, stresses are developed which makes the workpiece stand the chances of deformation thereby resulting in structural defect and poor surface integrity. Hence, changes in the clamping force requirement can be controlled through automatic adjustment of the pressure in the pneumatic cylinder in a bid to meet up with the required surface and dimensional tolerances.

2. Materials and method
This work develops a fixture controlled by six pneumatic double-acting cylinders with delay timer. The response and effect of machining, as well as clamping forces, were also investigated. The parameters considered for the design of the fixture include the yield strength of the carbon steel material, required machining and clamping forces, mechanical properties of the workpiece, workpiece geometry or orientation, etc.. The choice of control systems and other materials employed was driven by the need to meet the design requirements. The use of pneumatic control systems play very significant roles in industrial automation systems because of the advantages of easy maintenance, cleanliness, low cost of production, availability and low energy consumption (Ahn & Yokota, 2005; Denkena, Dahlmann, & Kiesner, 2014; Ebel, Idler, Prede, & Scholz, 2010; Oladapo, Balogun, Afalabi, Azeez, & Asanta, 2015). Particularly this system uses a 24 V power supply as an energy source and operates on a low pressure of 600 kPa. This is common for most pneumatic control actuator system of double-acting cylinder (Oladapo et al., 2016).

2.1. The reconfiguration novelties
The reconfiguration novelties for the fixture are as follows:

1. Six adjustable double-acting pneumatic cylinders with delay timers. Compressed air is fed into the double-acting cylinders from both ends hence it can operate from both directions. The delay timer will enhance quick adjustment of the movement time and accurate return
during and after clamping. This will also enable the time to be preset as the work will be clamped for the time set thereafter giving way for automatic return after the preset time elapses. The double-acting used is actuated by a directional control valve with five ports and two switching positions. The solenoid coil is energized when the electric current is applied thus switching the valve. The cylinder on the left side is pressurized while the other on the right is exhausted forcing the piston rod to advance. On the contrary, the solenoid coil is de-energized as soon as the left side is exhausted and the right is pressurized thereby making the cylinder to retract. When the cylinder is no longer fed with current, the valves automatically switches back to its position causing the piston rod to retract.

(2) A Programmable Logic Controller (PLC) within the electro-pneumatic which controls the six cylinders at once having the same memory for workpiece centralization during operation. This will check workpiece deflection.

(3) A magnetic proximity switch which allows gentle clamping of workpiece. This will prevent distortion of work position that could damage the workpiece during operation.

(4) An adjustable smart clamping system with pneumatic control for the assembly fixture. To achieve this, a Smart Clamping Force Control (SCFC) system was simulated to understudy the working principles with the aid of FluidSIM 5.0 software and results obtained compared with experimental values and available literature. The finite element analysis of the fixture was also carried out using Autodesk Inventor to determine the structural stress of the system.

(5) The clamping sensor which helps to detect the material of the workpiece also allows it to move at a slow speed for the forward stroke. This is to allow clamping without damaging the workpiece. The SCFC (Smart Clamping Force Control) clamp system ensures that the degrees of freedom are restructured and that no deflection occurs.

(6) The use of solenoid actuated valves: This enhances automatic control by forming an interface between the pneumatic and electric controls. They are actuated via the output signal from the control signal unit which either opens or shuts off the connections in the pneumatic power section. They connect or shut off the supply of compressed air thereby advancing or retracting the cylinder drives during clamping and unclamping stages.

In contrast, with conventional fixture without automatic controls, the incorporation of these novelties and control technologies in the reconfigurable fixture prevents buckling, deflection or distortion, and enhances gentle, quick, precise and automatic clamping as well as retraction of clamping force after machining operations while ensuring adequate clamping force, high degree of flexibility and interchangeability, good surface finish with resulting reduction in the production cycle time. This work finds application in production industries as a work holding device for low weight components limited to 15 kg during machining or shaping operations such as filing, boring, drilling, grinding, cutting, etc..

The design calculations involving force exerted by the piston, the theoretical piston force, effective force for the forward and return stroke, usable piston ring area, air compression ratio, air consumption, etc., have been carried out manually while other calculations involving stress analysis was done with the aid of solid works design and modeling tool.

2.2. Materials and method

The choices of dimensions of the fixture components were influenced by the results of design calculations while the choice of control systems and other materials employed was driven by the need to meet the design requirements. The framework for the development of the pneumatically controlled work holding system is shown in Figure 2.

The materials employed for the development is presented in Table 1.
2.3. Design calculations

The fixture is designed to hold a workpiece whose maximum mass is limited to 15 kg. The piston force exerted by an operating element depends on the air pressure, the cylinder diameter and the frictional resistance of the sealing elements. According to Ebel et al. (2010), the theoretical piston force is expressed by Equation (1).

\[ F_{th} = A \cdot P \]  

where;

\( F_{th} \) is the theoretical piston force (N); \( A \) is the usable piston area (\( m^2 \)); and \( A \) is the usable piston area (\( m^2 \)); and \( P \) is the working pressure (\( Pa \))

The usable piston area is expressed as Equation (2)

\[ A = \frac{\pi D^2}{4} \]  

where;
The piston diameter for the two big double-acting cylinder of length 0.3 m is 0.02 m, hence from Equation (2), the usable piston area is calculated as $3.142 \times 10^{-4} \ m^2$.

The working pressure is 600 kPa, therefore the theoretical piston force is calculated as $188.52 \ N$ from Equation (1). Taking the frictional forces to be 10% of the theoretical piston force

the frictional forces $F_R = 18.852 \ N$.

The effective force for the forward stroke is expressed by Equation (3).

$$F_{eff} = A \cdot P - F_R$$

$$F_{eff} = 188.52 - 18.852$$

$$F_{eff} = 169.668 \ N$$

The effective force for the return stroke is expressed as Equation (4).

$$F_{eff} = A^{' \cdot P - F_R}$$

where;

$A^{'}$ is the usable piston ring area ($m^2$) expressed as Equation 5

$$A^{'} = (D^2 - d^2) \frac{\pi}{4}$$

where;

$d$ is the piston rod diameter (0.008 m)

The usable piston ring area $A^{'}$ is calculated as $2.639 \times 10^{-4} \ m^2$ from Equation (5), while the effective force $F_{eff}$ is calculated as $139.50 \ N$

Similarly, the piston diameter for the four small double-acting cylinder of length 0.2m inclined at an angle 45° is 0.016 m, hence from Equation (2), the usable piston area is calculated as $2.01 \times 10^{-4} \ m^2$.

The working pressure is 600 kPa, therefore the theoretical piston force is calculated as $120.65 \ N$ from Equation (1). Taking the frictional forces to be 10% of the theoretical piston force

the frictional forces $F_R = 12.065 \ N$.

The effective force for the forward stroke is calculated from Equation (3) as

$$F_{eff} = A \cdot P - F_R$$

$$F_{eff} = 120.65 - 12.065$$

$$F_{eff} = 108.585 \ N$$

The usable piston ring area $A^{'}$ is calculated as $1.728 \times 10^{-4} \ m^2$ from Equation (5), while the effective force $F_{eff}$ is calculated as $91.621 \ N$.

The piston speed of the pneumatic cylinders is dependent on the counter forces, the prevailing air pressure, the tube length, the tube cross-section between the control element, the operating element, the flow rate through the control component as well as the end position cushioning. The average speed of the cylinder is 1.0 m/s.
The air compression ratio is expressed as Equation (6).

\[
\text{Compression ratio (C.R)} = \frac{101.3 + \text{working pressure}}{101.3}
\] (6)

The compression ratio is calculated as 5,924,000

The air consumption in m\(^3\)/sec is expressed by Equation (7).

\[
\text{Air consumption} = \frac{C.R \times A \times S \times S'}{C_0 / C_1}
\] (7)

where;

\(S\) is the stroke length (1 m) and \(S'\) is the stroke per sec (0.016 sec\(^{-1}\))

The air consumption from Equation (7) is calculated as 29.79 m\(^3\)/sec for the big cylinder.

Similarly for the small cylinder, the air consumption is calculated as 19.33 m\(^3\)/sec.

Since the effective force for the forward stroke is calculated as 169.668 N, the maximum mass of workpiece the fixture can hold is limited to 15 kg using a safety factor of 1.2. From the calculations above, the effective clamping force on either of the stroke is a function of the piston area and the pressure in the pneumatic cylinder thus the choice of the pneumatic cylinder is informed from the calculations of the effective clamping force required using a safety factor of 1.2. Hence, since the effective return and forward stroke ranges between 140 and 170 N, four 16 × 200 mm double-acting cylinders and two 20 × 300 mm double-acting cylinder were selected. These specifications will satisfy the process requirements and ensure satisfactory clamping under different machining conditions. The fixture development also consists of the fixture planning, layout design, elements or components design. This is to ensure minimum number of components of fixture components to prevent interference with the tool or workpiece during operation. This will also pave for smart location, multiple machining operations and efficient control of the system. The right configuration, sequence and orientation of the fixture’s locator, clamp and support as well as other elements in order to obtain the desired spatial relationship with the tool and workpiece during machining operation are design factors considered in order to achieve the goal of reduction in the overall machining cycle time. The use of pneumatically controlled cylinder for work holding in this design ensures the workpiece is totally and safely constrained without any movement. The clamping force holds the workpiece after location and the workpiece remains in a position of static equilibrium to withstand all machining forces without deformation or distortion. The isometric view of the reconfigurable fixture using pneumatic cylinders is shown in Figure 3 as well as its part list presented in Table 2 while the orthographic view is shown in Figure 4 respectively.

2.4. Description of the reconfigurable fixture

The job holder locates the workpiece and transmits the required clamping force from the cylinders clamp to the workpiece. The pneumatic cylinders are supported in order to eliminate vibration or deflection of the piston rods during operation. The cylinder supports are subjected to compressive forces equal to the weight of the cylinder. The base plates of the cylinder clamp and movable supporting cylinders are fitted to the movable frames of the fixture assembly by means of bolts and nuts. A solenoid actuated control valves is placed at the interface between the two parts of the pneumatic control system. They are switched ON by outer signals from the signal control section and switched OFF by opening connections in the pneumatic power section. The double-acting cylinder is actuated by a directional control valve with ports and two switching positions. When the directional control valve is in its initial position, the left cylinder chamber is exhausted and the right cylinder chamber is pressurized, leaving the piston rod unmoved. On the other hand, when the directional control valve is actuated, the left cylinder chamber is pressurized and the right cylinder chamber is exhausted, then the piston rod advances. The pneumatic hose allows the
Figure 3. Isometric view of the reconfigurable fixture.

Table 2. Part list

| S/N | Description             | S/N | Description          | S/N | Description                          |
|-----|-------------------------|-----|----------------------|-----|--------------------------------------|
| 1   | Surface plate           | 4   | Side braze           | 7   | Job holder                           |
| 2   | Cylinder support        | 5   | Stand                | 8   | 5/2-way double solenoid valve        |
| 3   | Double-acting cylinder  | 6   | Movable frame        | 9   | Control board                        |

Figure 4. Orthographic view of the reconfigurable fixture.
maximum air of $10 \times 10^5$ Pa and the pneumatic cylinders requires $6 \times 10^5$ Pa of air pressure. The pneumatic hose is connected to both sides of the throttle and to the one-way flow control valve. The throttle valve is used for controlling the operation speed of driving cylinders and the movement of assembly components such as the pneumatic cylinder. The force transferred to the piston rod is slightly greater for the forward stroke than for the return stroke to ensure adequate clamping as well as satisfactory rigidity and strength during the clamping operation.

3. Result and discussion
The reconfigurable fixture is designed to locate and hold the workpiece using the four job holders that are moved by the four pneumatic cylinders and two other pneumatic cylinder that moves the cylinder support. The developed reconfigurable fixture is shown in Figure 5.

The finite element analysis carried out using Inventor simulation is shown in Figure 6 and the result is presented in Table 3, respectively.
From Table 3, the deformation per unit length is small and negligible. This points to the fact that the clamping force is sufficient to prevent distortion. Also, the stress induced on the fixture is less than the yield strength of the material. This implies that the fixture is unlikely to yield to stress during operation.

3.1. Evaluation of the reconfigurable fixture on FESTO fluid SIM

The setup is tested on the FESTO fluid SIM. Figures 7 and 8 show the running of the reconfigurable fixture on FESTO fluid SIM (activated and un-activated).

3.2. Circuit connections of the setup on FESTO fluid SIM

The circuit is connected to control the assembly fixture and to move the piston of the cylinders. In the circuit connection, the un-activated circuit is opened while the activated circuit is closed. The circuit connection of the un-activated and activated setup is shown in Figures 9 and 10 respectively.

Figures 11 and 12 show the representation of the simulation and experimental result of the signal control for the pneumatic control.

Table 3. Results obtained from the finite element analysis.

| Name         | Type                        | Min         | Max         |
|--------------|-----------------------------|-------------|-------------|
| Strain 1     | ESTRN: Equivalent Strain    | 2.26322e-016| 5.58621e-007|
|              | Element: 2491              |             |             |
| Stress1      | VON: von Mises Stress       | 2.378e-007  | 2.251 + 007 N/m² |
|              | Node: 33,371               |             |             |
| Displacement1| URES: Resultant Displacement| 0 mm        | 8.77695 mm  |
|              | Node: 315                  |             |             |
| Yield Strength|                            |             | 6.20422e + 008 N/m² |
| Tensile strength |                        |             | 7.23826e + 008 N/m² |

Figure 7. Un-activated setup on FESTO fluid SIM.
3.3. Discussion of results

The values of position, velocity, acceleration and pressure were determined from the graph of the FESTO Fluid SIM (Figures 10 and 12). The pressure compressed at the supply is \(6 \times 10^5\) N/m\(^2\) while the maximum force for the forward stroke is 120 N. The force transferred to the piston rod for the forward stroke is greater than that of the return stroke (80 N). This is due to the fact that the forward stroke requires greater force for adequate clamping operations hence the cross-sectional area of the piston side supplied with compressed air is greater than the piston rod side. The opening level of the one-way flow control valve remains at 100% (fully opened) when the circuit is opened and closed.

3.3.1. Position

On the graph of the setup, when the circuit is opened on the FESTO fluid SIM and the delay timer used to preset a clamping time of five secs, the position of the double-acting cylinder moves from zero and approaches the workpiece at a maximum position of 100 mm and when the circuit is closed on the FESTO fluid SIM the position of the double-acting cylinder moves a maximum position from 100 mm to 0 as shown in Figures 11 and 12. This implies that the fixture can quickly...
locate and hold the workpiece at a position of 100 mm within five secs. This point to the fact that the fixture is characterized with high speed and smart clamping which in turn will reduce the overall machining cycle time.
3.3.2. Velocity
The velocity of the double-acting cylinder increases as the circuit is opened, it increases from 0 to 1.40 m/s⁻¹. When the circuit is closed it returns back to zero as shown in Figures 11 and 12. The velocity of the double-acting cylinder is in the positive direction; hence, the cylinder approaches the workpiece at a maximum velocity of 1.4 m/s in the positive direction at a maximum force of 120 N for the forward stroke. This also implies that the developed fixture can operate with sufficient speed and accuracy. This will reduce the machining cycle time with attendant increase in the productivity.

3.3.3. Acceleration
The acceleration of the double-acting cylinder falls below — 593 m/s² and when the circuit is opened (activated). When deactivated, the acceleration of the double-acting cylinder moves beyond 839 m/s² as shown in Figures 9 and 10. The rate at which velocity changes with time was observed to decrease in the negative direction when the circuit is opened and increases in the positive direction when the circuit is closed. Since acceleration is a function of velocity and time, it then implies that the speed of operation for the forward stroke is lesser than that of the return stroke. This is because of the introduction of the internal braking system to enhance gentle clamping of the workpiece in order to prevent deflection, displacement or distortion.

4. Conclusion
The reconfigurable fixture is an improvement of existing ones as it balances operator’s safety and comfort with cost effectiveness, precision, accuracy and smart location. The existing ones limited to manual or hydraulics are not as flexible or adjustable as the ones controlled with pneumatic cylinders. The only limitation being its restriction to low weight operations. The reconfigurable fixture designed with the use of pneumatic double-acting cylinders, 5/2-way solenoid valves, and one-way flow control valve ensures high flexibility and smooth clamping. The electro-pneumatic controls facilitate the holding and locating of work piece during machining operations while reducing production time and cost. This work finds application in production industries as a work holding device for low weight components limited to 15 kg during machining or shaping operations such as filing, boring, drilling, grinding, cutting etc. The clamping force is enough to withstand operational and loading forces without buckling, deflection or deformation because the maximum stress induced was found to be lower than the yield strength of the material, hence, the fixture combines high flexibility with satisfactory clamping rigidity and strength. Future work can consider the optimization of both the process and machining parameters for optimum performance.

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