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Performance Evaluation of a Smart Welding Fixture and Jig Assembly

Palesa S. Sibanda[1]

Tshwane University of Technology, Pretoria, South Africa, sibandapalesa@gmail.com

Ilesanmi A. Daniyan[2]

Achievers University, Owo, Nigeria, afolabiilesanmi@yahoo.com

Khumbulani Mpofu[3], Elvis P. Sekano[4], Walter T. Seloane[5]

Tshwane University of Technology, Pretoria, South Africa, mpofuk@tut.ac.za, sekanoep@tut.ac.za

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Abstract **- The increasing global competitiveness, dynamic customers' and markets requirements as well as the bottom-line of profitability necessitate the use of smart welding fixture and jigs as work holding and locating devices during component parts manufacturing. This study presents the performance evaluation of a smart welding fixture and jig for welding operation. The smart welding fixture and jig assembly consists of a compressor, proximity sensors, thermostat, cooling system, clamping elements, fixture body support, cables as well as a control panel for pre-programming the conditions for the welding operation. The performance evaluation was carried out by comparing the pressure and the time taken for clamping and unclamping activities. The pressure selected for the evaluation ranges between 241 316.6 Pa - 792 897.4 Pa while measurement was taken in terms of the time it took the edges-gripping clamps to return to their initial states. The results obtained also show that at as the pressure increase, there was a decrease in the time taken for the clamping and unclamping activities up to 379 211.8 Pa. Further increase in the pressure beyond 379 211.8 Pa first resulted in an increase in the time taken up to 792 897.4 Pa. When the pressure was increased beyond 792 897.4 Pa, it was observed that the time taken for the clamping and unclamping activities begin to increase and later reduces. The machine demonstrated the potential for saving 32.26% of the total time during the manual operation when the machine is operated in an automatic mode. This study provides empirical findings that can assist manufacturing industries particularly those who employ welding as a means of product fabrication in achieving welding operations in a timely and cost effective manner with less human intervention.**

Index Terms **- Clamping and unclamping activities, Fixture and jig assembly, Sensors, Welding operation**

Introduction

Welding fixture and jig is an ample supporting equipment that is necessary in assembly lines in a work place especially those associated with thermal joining processes [1].

According to Wang *et al*. [2], welding fixtures play significant role in the product development, quality, productivity and cost. The jig controls and direct the tool into the workpiece at a pre-determined location in the system. It is usually designed to limit the blank in the working zone of the machine tool. They usually have stoppers that can prevent horizontal movement of parts and guides that can ensure correct positioning of the tool. Fixtures on the other hand are supporting and locating devices. It fixes the workpiece in the right position and ensure that there is no part movement during assembly operation. Both jig and fixtures have locators to constrain the degree of freedom of the workpiece as well as support elements to minimize part deformation. Welding jigs are designed to withstand a large number of loading and unloading cycles throughout their lifetime. Due to this, welding jigs must be adjustable. The increasing global competitiveness, dynamic customers' and markets requirements as well as the bottom-line of profitability necessitate the use of smart welding fixture and jigs as work holding and locating devices during component parts manufacturing [3]. To address these challenges, there is a need to automate the manufacturing systems for economies of scale, cost efficiency and an increased production. However, there are many prototypes and innovations that are not used by their targeted users, thereby resulting in a slow growth and adaption to the new technologies and systems. South Africa for instance, has a lot of novel ideas that can promote smart manufacturing that are fully implemented. Prototypes are developed to enable the translation of creative thoughts and ideas to products that will contribute towards the market's and economic growth.

To reduce production costs there are a few things to be considered in the process of developing a smart welding machine. These include minimizing welding deformation in an efficient way.

This can be achieved by calculating and tracking the performance on the fixture jig while operating. An established smart welding fixture and jig design is very important in order to achieve a machine that will produce quality products, therefore it is crucial to know and understand the different types of forces, measurements and accuracy of the machine [4]. This will then assist in solving most of the problems companies face from end production to the next. This is mostly caused by bottlenecks such as misalignment that are usually not visible and most companies lose a lot of money at a later stage trying to repair or replace people and/or machines. The right information about the force, measurements and accuracy can assist in the elimination of these bottlenecks.

Modern manufacturing systems are characterized by an increase in the level of intelligence compared to the traditional systems. This is to enable the system adjust in real time to the manufacturing demands, product customization and batch production. There is a need for the development of intelligent assembly system that can facilitate interchangeability, easy loading and unloading, quick workpiece location with adequate clamping force. Furthermore, where it is required to manufacture a product with different parts and sizes, that need specialized clamping, intelligent system can offer a robust solution in this regard. Some existing studies have reported on the development of jig and fixture systems. For instance, Zhang *et al.* [5] developed a novel reconfigurable assembly jig based on stable agile joints and adaptive positioning clamping bolts. The system consists of a framework locators and other auxiliary elements while Qin *et al.* [6] proposed a reconfigurable jig assistant assembly system to enhance human-machine collaboration and to increase the automation level during assembly operation.

Park *et al.* [7] developed a pin array fixture system for part position optimization. The system can locate the optimal position for the installation of assembly part. However as the system becomes complex product quality may reduce due to the use of transformable fixtures compared to the conventional fixture. Hence the need for system's reconfiguration. Hogreve *et al.* [8] developed an assembly jig for large scale production. The developed jig has three major features namely mobility, modularity and adaptivity. The jig was designed with ergonomic features to aid the personnel producing high lift system in civil aircraft applications. Zuperl and Cus [9] indicated that the incorporation of fixture analysis module as an integral part of an intelligent fixturing system is important. Zheng and Wang [10] proposed the box-joint based reconfigurable and flexible tooling technology to aid assembly and manufacturing operations. Zhinzhen *et al.* [11] developed a customised fixture for aerospace application. Specifically, a fixture for the development of space flight valve shell. Daniyan *et al.* [12] carried out the design and structural analysis of a flexible and reconfigurable welding jig for assembly operation in the railcar industry.

The results obtained that the developed jig can assemble top and lower brackets of a railcar, although some level of automation and intelligence is still required to promote its functionality.

Table I presents the summary of some existing works.

TABLE I
SUMMARY OF THE LITERATURE REVIEW ON SMART FIXTURES AND JIGS

S/N	Contribution	Methodology	References
1.	Development of light weight fixture for holding workpiece during assembly operations.	Computer aided design, fabrication and performance evaluation	[13]
2.	Conceptual designs of intelligent reconfigurable welding fixture for rail car manufacturing industry	Conceptual design coupled with computer aided designs	[14]
3.	A framework for a Reconfigurable Welding Jig for Sheet Metal Panel Component of a Railcar.	Conceptual design coupled with computer aided designs	[15]
4.	Conceptual design of modular fixture for frame welding and drilling process integration	Conceptual design coupled with computer aided designs	[16]
5	Towards the improvement of machining fixture design	A case-based reasoning paradigm	[17]
6	Design and testing of the different interfaces in a 3D printed welding jig.	Computer aided design and experimental validation	[18]

Jigs and fixtures are employed during manufacturing process such as assembly or machining operations to ensure repetitive workpiece orientation, clamping and positioning. They offer significant impact during manufacturing processes such as high part repeatability, reduction in the manufacturing cycle time and cost effectiveness. They also ensure quick workpiece location, part interchangeability and improvement in product's quality.

Despite these merits, a poorly designed jig and fixture can have a negative impact on the manufacturing process. It could lead to quality issues such as poor product orientation, dimensional inaccuracy and geometrical defects. This may affect the service requirements of the final product thereby leading to rejection or reverse engineering. As manufacturing industries strive to achieve profitability, precision, good product quality and reduction in the manufacturing lead time, attention needs to be paid to the development of intelligent and ultra-precision assembly systems. To effectively assemble a part, there is a need for a system that can locate and hold the workpiece. Gameros *et al*. [19] underscore the importance of jig and fixturing elements to modern manufacturing systems and proceses. Gameros *et al.* [19] classified the basic functions of workholding into three namely: part location (to constrain the degree of freedom of the workpiece and its orientation via the use of locators), clamping (to keep the parts in the correct position against manufacturing forces) and auxiliary functions. Auxiliary functions could include support (to minimize part deformation) and tool interaction (to guide the tool. Morgan *et al.* [20] indicated that to achieve the automation of complex, customised and individual manufacturing systems and processes, that will enable flexibility in production capacity and functionality, there is a need for the development of intelligent and reconfigurable systems. The reconfigurability will enable modularity and scalability thus making the system responsive to changes in demand while the system's intelligence will aid independent decision making on the areas to be adjusted. As a result, an integrated technology could serve as the enabling interface technology. Most of the existing work focussed on the development of jigs and fixtures as separate assembly system but this study integrated the two systems to promote manufacturing efficiency as well as to save time and cost. Thus, the objective of conducting performance evaluation on the smart welding fixture and jig prototype is to aid the effectiveness of the welding location through quick location as well as load and unloading of component parts with minimal human intervention. This will promote the time and cost effectiveness of the assembly operation and also reduce the manufacturing lead time. The developed prototype of the smart welding fixture and jig is also evaluated to ensure that its components fit into the designated station, as each station has its specifications. The evaluation will also aid the understanding of the forces and pressures requirements at each station to ensure that the final product meets the service requirements.

The novelty of this work lies in the fact that the performance evaluation of systems that combines the features of an automated welding fixture and jig has not been sufficiently highlighted by the existing literature.

MATERIALS AND METHOD

The methodology employed is the experimental design approach.

It consists of the evaluation procedure for investigating the performance of the developed machine in the manual and automatic modes of operation. The performance evaluation of this fixture involves an assessment of various factors such as clamping force, effective force and time taken for the clamp operation.

I. Machine's Description

In this experiment, the machine is set to operate manually and automatically so as to investigate the differences in the operational capacity for both modes.

The developed welding fixture shown in Figure 1 was manufactured from aluminium 6082T6 alloy. Aluminium 6082T6 was used because of its lightweight and its ability to rapidly dissipate heat. A coat of Teflon was used to create a non-stick surface and to mitigate the adherence of welding splatter on the fixture during welding.

The smart welding fixture and jig assembly consists of a compressor, proximity sensors, thermostat, cooling system, clamping elements, fixture body support, cables as well as a control panel for pre-programming the conditions for the welding operation. The performance evaluation was carried out by comparing the pressure and the time taken for clamping and unclamping activities. The pressure selected for the evaluation ranges between 241 316.6 Pa - 792 897.4 Pa while measurement was taken in terms of the time it took the edges-gripping clamps to return to their initial states.

The design of this smart welding fixtures and jig system is meant to improve productivity and efficiency of the welding operation. The system consists of four stations with a set of proximity sensors and edge-gripping clamps at each station. This is because jigs are mostly used to avoid rotation and disfigurement in the front of welding heat sources [21]. The proximity sensors were installed for a brief introduction of automation in the machine, whereby if there is no work piece on a certain station the sensor's light flickers and when it detects the work piece on its station the sensor's light becomes stable. To minimise any bottlenecks, in minimize idle time while operating this system, the clamps on each station exerts a firm pressure depending on the material used. The main idea is to find the right force for each material used so the clamping force exerted on the piece does not damage the piece. The machine can be set to operate on automation mode or manual mode. Currently the machine needs human intervention continuously, from switching on the plugs, ensuring that right amount of pressure is exerted into the smart welding fixture and jig body, checking and changing the machine to work in manual or automated state. The machine does not select the type of parts that need to be placed at each station and does not have a welding tool that operates automatically after the part has been placed on the station. However, to automate the working process of the developed system, a robotic arm with pick and place capabilities can pick the workpiece and set it into the jig. The fixture will automatically clamp the part and the machine tool will commence the machining operation.

Once the machining process is completed the fixture will unclamp and the robotic arm will unload the part and place it in the next assembly line of operation. The developed integrated jig and fixture system has multiple jigs and fixture for holding and locating multiple components. The system is designed to constrain the degree of freedom of each of the components to be assembled relative to the end effectors. The fixture mechanism uses pneumatic drive while the jig and fixture drive can be controlled either manually or automatically via the central control.

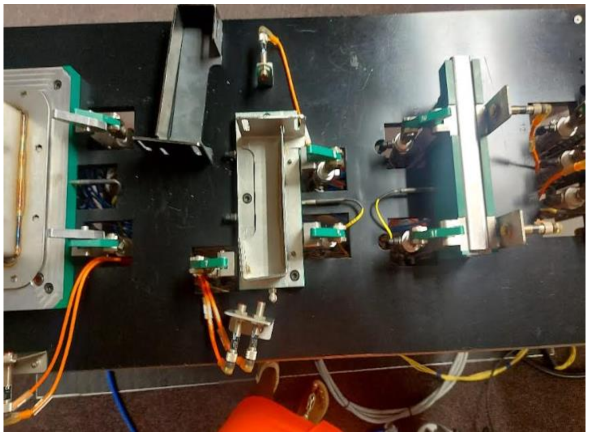

FIGURE 1 THE DEVELOPED WELDING FIXTURE

II. Operational Specifications

The essence of the calculations reported in this section is assist our customers and operators to know the optimum range of values of some important parameters such as pressure when starting the machine in order to meet the objectives of the machine such as: the required amount of perfectly welded parts at a specified time, and the amount of force that is applied on each part when it is clamped, the specified product quality amongst others.

This will promote the development of parts that meet customer satisfaction and quality criterion as the amount of damaged parts due to ineffective clamping system may contribute to the wastes in the production system. It is necessary to know the importance of the edge gripping clamps as they play a role in avoiding the parts placed at each station to slide away. It also prevents the parts being welded in wrong areas, and amongst others it also prevents the parts from moving up, down, vertical or in the horizontal direction during welding operation. There is a high chance of the part changing shape if it is not placed and clamped correctly with the right amount of force. This will result in the production of unreliable parts which may result in loss of reputation, goodwill and customer dissatisfaction. The clamps are added in positions where the speed of the welding tool will not affect the final product. The number of support points for each station for this machine was to enable gripping during the clamping and unclamping activities.

The cylinder type employed for the development of the fixture and jig assembly is the single acting type. It requires the operator to charge is after every experiment so that it will work more effectively and produce accurate results. It is note-worthy to mention that the developed fixture and jig is limited to small and light weight parts and cannot accommodate large heavy parts. The speed of the clamping and unclamping of the machine depends on the amount of air pressure from the 63.4 kg compressor.

Equation 1 is the expression used for the computation of the pressure (P) applied to the compressor [22].

$$P = \frac{F}{A} \qquad (1)$$

Where F is the force applied (N), D is the diameter of air compressor (40.35 mm) and A is the cross sectional area of the cylinder (mm^2) as expressed as $\frac{\pi D^2}{4}$

Figure 2 shows the air compressor of the developed fixture and jig assembly having a weight 63.4 kg and driven by a motor with a voltage capacity of 230 V.

FIGURE 2 THE COMPRESSOR OF THE DEVELOPED FIXTURE AND JIG ASSEMBLY

The following are the procedural steps undertaken during the performance evaluation of the developed fixture and jig assembly:

The three plugs connected to the power supply and the control panel were witched ON. The preferred mode of operation of the machine was selected from the control panel; either manual or automatic. The compressor was also powered, and it was ensured that the pressure reached the desired range between 15-115 psi as indicated on the compressor gauge. To get the exact pressure from the compressor, the pressures were measured to be measured 5 units higher than the exact pressure required due to loss of pressure as it travels from the compressor to the smart welding jig fixture itself.

The material to be clamped (2 mm by 2 mm stainless steel) were set on the machine. The timer was also set to count the time for the clamping and unclamping of the material to be clamped. For the automatic mode, the start button on the control panel is activated, and edge gripping feature of the machine clamps and unclamps the material from station 1 to 4 and the time to taken for the clamping and unclamping were taken. For the manual mode of operation, the edge gripping was done manually, and the time taken was also taken.

The area of the cylinder in m^2 is calculated from equation 2 thus;

$$A = \frac{\pi D^2}{4} \quad (2)$$

$$A = \frac{\pi X\ (0.04035)^2}{4}$$

A= 1, 2787 × $10^{-3}\ m^2$

Taking the applied pressure as 15 Psi (103421.4 Pa), the force for forward clamping and unclamping, is calculated as 132.245 N from Equation 1.

Considering the frictional effect and taking it to be 10% of the force applied, the reduction in the force due to friction is calculated as 13.225 N.

Thus, the effective force effective force for the clamping and unclamping is calculated thus;

Effective force = 132.245 – 13.225 =119.02 N.

The compression ratio is also calculated as follows:

$$CR = \frac{101.3 + 103421.4}{101.3}$$

Compression ratio is calculated as 1021.942

This calculation procedure was employed to compute the force for forward clamping and unclamping (N), effective clamping and unclamping force (N) as well as compression ratio for pressures 15-115 psi and the results obtained are presented in Table 2.

RESULTS AND DISCUSSION

Table II presents the time it takes the smart welding fixture jig to clamp and unclamp from station one to station four, excluding station three as there is no response from station three during this process both the manual and automatic modes of operation. When the machine is in manual mode all the stations respond accordingly. The time taken for the clamping and unclamping activities vis-à-vis the pressure released into the smart welding fixture jig is presented in Figure 3.

The results obtained also show that at as the pressure increase, there was a decrease in the time taken for the clamping and unclamping activities up to 379 211.8 Pa.

Further increase in the pressure beyond 379 211.8 Pa first resulted in an increase in the time taken up to 792 897.4 Pa. When the pressure was increased beyond 792 897.4 Pa, it was observed that the time taken for the clamping and unclamping activities begin to increase and later reduces. The time taken for the clamping and unclamping increased at lower pressures (pressures less than 379 211.8 Pa). The optimum pressure was found to be 379 211.8 Pa. However, beyond this optimum pressure, there was a slight increase in the time taken for the clamping and unclamping activities which can be traced to pressure loss due to frictional effects. Table II shows that 32.26% of the total time during the manual operation can be saved when the machine is operated in an automatic mode. This implies that the developed machine is time effective.

It is clearly seen that it is always better to opt for automation rather than manual. This saves time, money, and effort which will in turn help the businesses grow.

The time taken when the machine knob is on manual is unstable as it depends on the speed of the operator. The time it takes the operator operating the control panel to touch the button on the screen in order to close and open the clamps will either increase or decrease the total time taken by the machine for the clamping and unclamping activities. It was noted that the clamps lose power during its opening and closing due to the pressure drop during the experimental trials. The pressure loss can be attributed to the slow pace of the operator and this can affect the time taken for the closing of the clamps.

The pressure is not charged because it still falls under the same pressure test. This indicates that there is possibility for idle time under the manual mode of operation which can be eliminated when the machine is operated automatically.

An interesting fact about this machine is the need for periodic charging. The machine should not be left idle without recharging it. This might be beneficial to entrepreneurs to grow their businesses. When the machine is not properly charged, it will take longer time to clamp and unclamp the workpiece coupled with the fact that the machine may not operate as desired.

The smart welding fixture and jig shows great potential for saving a lot time and cost. The smart welding fixture and jig eliminates the need for rework and checking of joints of the work piece, it offers quality work by giving out a smooth part with no lumps whatsoever. These findings are in line with existing works which indicated that the automation of workholding systems can promote operational efficiency, significant time and cost savings as well as precision and accuracy of the final product [].

Denkena *et al.* [23] indicated that the integration of sensors as part of the fixturing elements will increase the smartness and intelligence level of fixtures while Wang and Romg [24] proposed the case-based reasoning method for computer-aided welding fixture design to aid its decision making.

TABLE II
CLAMPING AND UNCLAMPING FORCES AND COMPRESSION RATIOS

S/N	Pressure (Psi)	Pressure (Pa)	Force for forward clamping and unclamping (N)	Effective force (N)	Compression ratio	Time taken for automated mode (sec)	Time taken for manual mode (sec)	Difference in time taken (sec)
1	15	103421.4	132.245	119.02	1021.942	13.17	18.48	5.31
2	35	241316.6	308.572	1021.942	2383.197	12.84	18.47	5.63
3	55	379211.8	484.898	436.408	3744.453	11.77	18.37	6.60
4	75	517107	661.225	595.102	6466.965	12.44	18.52	6.08
5	95	655002.2	837.551	753.796	6466.965	12.56	18.55	5.99
6	115	792897.4	1013.878	912.49	7828.220	12.35	18.52	6.17
				Total		75.13	110.91	35.78

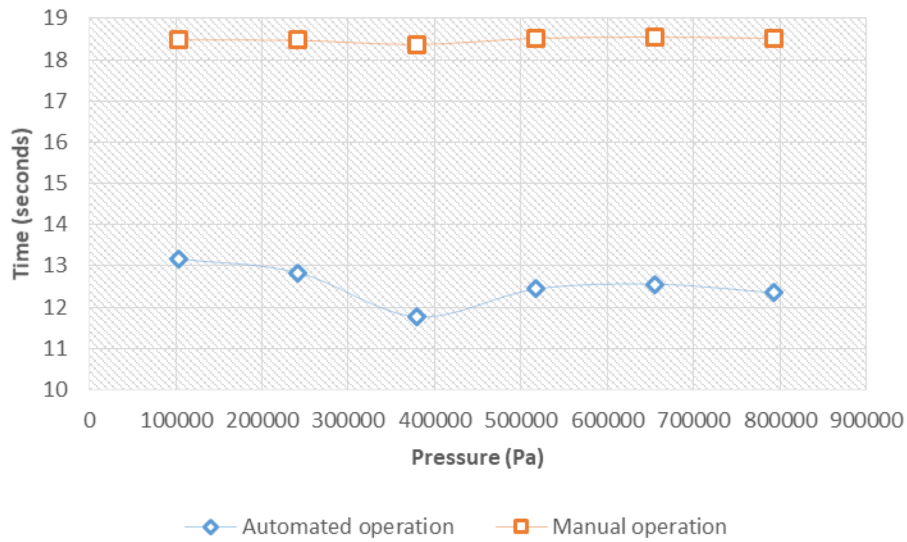

FIGURE 3 TIME TAKEN VS PRESSURE ANALYSIS

The calculation of the clamping force, will assist operators determine the type of material that can be used when working with this machine. The speed of the clamps on the machine is found to be directly proportional with the pressure from the air compressor. The higher the pressure the faster the clamps will clamp and unclamp until they reach an optimum pressure of 379 211.8. Beyond the optimum pressure, the relationship between the speed of the clamp and the pressure then becomes indirectly proportional, due to frictional effects.

The amount of pressure lost when air moves from the air compressor to the machine can have a negative impact on the performance of the machine, it is therefore important to take into account how the air compressor and pipes transporting the air works. When charging the machine, the pressure needs to be carefully monitored otherwise there will be a high chance of faults in each process performed.

CONCLUSION AND RECOMMENDATIONS

This aim of this study was to evaluate the performance evaluation of a smart welding fixture and jig for welding operation.

This was achieved by comparing the pressure and the time taken for clamping and unclamping activities. The pressure selected for the evaluation ranges between 241 316.6 Pa - 792 897.4 Pa while measurement was taken in terms of the time it took the edges-gripping clamps to return to their initial states. The machine demonstrated the potential for saving 32.26% of the total time during the manual operation when the machine is operated in an automatic mode.

The developed smart welding fixture and jig can promote the reliability and accuracy of the welding operation. The machine is also safe when operated either in the automated or manual mode with sufficient clamping of the workpiece and other machine's component prevent accidental fall.

The smart welding fixture and jig shows great potential for saving a lot time and cost. The smart welding fixture and jig eliminates the need for rework and checking of joints of the work piece, it offers quality work by giving out a smooth part with no lumps whatsoever. The machine's automation can be improved further by conducting more experiments and calculations along with a few observations thereafter. The machine can be set to go high than the optimum pressure 379211.8 MPa so to increase production. More features such as pick and place capabilities can be added to the machine to enable it carry out simultaneous operations. This will enable the machine identify and pick the correct work piece for each station, and place it in the correct station for automatic welding operation. Further research can consider the testing of the developed machine for more performance evaluation as this will help to identify and address some of its limitation.

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Gibela research chair, Tshwane University of Technology (TUT), Pretoria, South Africa.

REFERENCES

[1] Mulyadi, I. H., Putri, N. T. and Muhammed, F. Designing of welding jig for productivity improvement and cost-savings in thresher's cover assembly: A case study on CV Citra Dragon assembly plant. IOP Conference series: Materials Science Eng. Vol. 602(012047), 2019, pp. 1-8.

[2] Wang, H., Rong, Y., Li, H. & Shuan, P. Computer-aided fixture fixture design: Recent research and trends. Computer Aided Design, 42, 2010, pp. 1085-1094.

[3] Taufik, R. S., Hirmanto, S., Sivarao, H. A., & Tajul, A. A. Design of jigs and fixtures for hydraulic press machine. Malikussaleh Industrial Engineering Journal, Vol. 1, No. 1, pp. 19–24.

[4] Ma, N., Huang, H. and Murakawa, H. Effect of jig constraint position and pitch in welding deformation. Journal of Materials, Vol. 221, 2015, pp. 154-162.

[5] Zhang, H., Zheng, L., Chen, X., & Huang, H. A novel reconfigurable assembly jig based on stable agile joints and adaptive positioning-clamping bolts. Procedia CIRP, 2016, Vol. 44, pp. 316–321.

[6] Qin, Z., Lu, Y., Zhang, H. Liu, X. & Zheng, L. A reconfigurable jig assistant assembly system based on wearable devices. 15th International Science and Engineering Conference. Virtual conference, 2020.

[7] Park, J. W., Park J. & Kim, H. Assembly part positioning on transformable pin array fixture by active pin maximization point and joining point alignment. IEEE Transactions on Automation, Science and Engineering, Vol. 19, No. 2, 2021, pp. 1047-1057.

[8] Hogreve, S. Krist, K. & Tracht, K. Mobile modular and adaptive assembly jigs for large-scale products: In Schuppstuhl, T., Tracht, K. and Raatz, A. (eds.) Annals of Scientific Society for Assembly, Handling and Industrial Applications, 2021, Springers Cham, pp. 39-50.

[9] Zuperl, U. & Cus, F. Fixture analysis module, an essential element of the intelligent fixturing system. Journal of Production Engineering, Vol. 16, No. 1, 2012, pp. 31–34.

[10] Zheng, L., & Wang, J. Development and application prospects of boxjoint-based reconfigurable and flexible tooling technology. Aeronautical Manufacturing Technology, Vol. 18, 2013, pp. 26–31.

[11] Zhizhen, Z., Fangkai, D., Yikun, S., Shaofai, Y., & Fuwei, Y. Design of special fixture for spaceflight valve shell workpiece. Journal of Manufacturing Technology and Machine Tools, Vol. 10, 2017, pp. 115–118.

[12] Daniyan, I. A., Makinde, O., Ramatsetse, B. I., Mpofu, K., Adenuga, A. O. & Saka, R. C. Design and structural analysis of welding jig for part family assembly of the top and lower brackets of a railcar. 2023 IEEE 14th International Conference on Mechanical and Intelligent Manufacturing Technologies, Cape Town, South Africa from May 26-28, 2023. IEEE Xplore, 2023, pp. 213-218. doi: 10.1109/ICMIMT52186.2021.9476195.

[13] Daniyan, I. A., Adeodu, A. O., Oladapo, B. I., Daniyan, O. L. & Ajetomobi, O. R. Development of a reconfigurable fixture for low weight machining operations. Cogent Engineering, Vol. 6, No. 1579455, 2019, pp. 1-17.

[14] Seloane, W.T., Mpofu, K., Ramatsetse, B. I. & Modungwa, D. Procedia CIRP, Vol. 91, 2020, pp. 583-593.

[15] Daniyan, I. A. Mpofu, K., Ramatsetse, B. I. & Makinde, O. A framework for a reconfigurable welding jig for sheet metal panel component of a railcar. 2021 IEEE 12th International Conference on Mechanical and Intelligent Manufacturing Technologies. 2022, pp. 73-80. Added to IEEE Xpore. doi: 10.1109/ICMIMT52186.2021.9476195.

[16] Darmawan, T. D., Priadythama, I. and Herdiman. Conceptual design of modular fixture for frame welding and drilling process integration case study: Student chair in UNS industrial engineering integrated practicum. AIP Conference Proceedings, Vol. 1931(030033), 2018.

[17] Hashemi, H., Awaludin, M. S. & Izma, S. To improve machining fixture design: A case-based reasoning paradigm. Journal of Basic and Applied Scientific Research, Vol. 3, 2013, pp. 931:937.

[18] Kampker, A., Bergweiler, G., Hollar, A., Lichtenthaler, K. & Leimbrink, S. Design and testing of the different interfaces in a 3D printed welding jig. Procedia CIRP, Vol. 81, 2019, pp. 45-50.

[19] Gameros, A., Lowth, S., Axinte, D., Nagy-Sochacki, A., Craig, O. & Siller, H. R. State of the art in fixture systems for the manufacture and assembly of rigid component: a review. International Journal of Machine Tools and Manufacture, Vol. 123, pp. 1-21.

[20] Morgan, J., Halton, M., Qiao, Y. & Breslin, J. G. Industry 4.0 smart reconfigurable manufacturing machines. Journal of Manufacturing Systems, Vol. 59, 2021, pp. 481-506

[21] Ma, N. and Huang, H. Efficient simulation of welding distortion in large structures and its reduction by jig constraints. Journal of Materials, Vol. 26, No. 1, 2015, pp. 5206-5216.

[22] Spotts, M. F. (1994). Design of machine elements. 7th Edition, London: Prentice Hall.

[23] Denkena, B., Dahlmann, D., & Kiesner, J. Sensor integration for a hydraulic clamping system. Processing Technology, Vol. 15, 2014, 465–473.

[24] Wang, H. and Romg, Y. (2008). Case-based reasoning method for computer-aided welding fixture design. Computer Aided Design, 40, 2008, pp. 1121-132.

AUTHORS' INFORMATION

Palesa S. Sibanda, Student, Department of Industrial Engineering, Tshwane University of Technology, Pretoria, South Africa.

Ilesanmi A. Daniyan, Associate Professor, Department of Mechanical & Mechatronics Engineering, Achievers University, Owo, Nigeria.

Khumbulani Mpofu, Professor, Department of Industrial Engineering, Tshwane University of Technology, Pretoria, South Africa.

Pule Sekano, Lecturer, Department of Industrial Engineering, Tshwane University of Technology, Pretoria, South Africa.

Walter T. Seloane, Researcher, Department of Industrial Engineering, Tshwane University of Technology, Pretoria, South Africa.