Design and Development of Spin Welding Machine for Thermoplastics

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Abstract. A new indigenous spin welding machine for thermoplastics with advanced mechatronic controls is conceptualised, designed in detail and a prototype is developed for joining of two thermoplastic parts in axis-symmetrical fashion. Manual spin welding machines for joining thermoplastic parts in axis-symmetrical manner are generally obtained by modifying drill type machines which causes the relative frictional rotation of parts under contact pressure exerted manually through a lever. The contact under relative motion causes the heat generation and results into fusion of parts. The joints from such machines exhibit inconsistency inherent in the manual process. The indigenous prototype machine is able to perform spin welding process with consistency. It enables the operator to choose and control the process parameters such as rotation velocity, time of rotation, spin pressure and cooling pressure.

Keywords: Design, Spin Friction Welding, Programmable Controls, Human Machine Interface, Thermoplastics.

1. Introduction

One of the major advantages of thermoplastics is the ease with which these can be molded, incorporating small and intricate features integrated within them [1-2]. However, when the complexity requirement of the thermoplastic product cannot be met in a single molding operation and require multiple parts to be joined into one, joining process such as plastic welding comes handy [3-5]. Friction spin welding has emerged as a popular method of joining thermoplastic parts axisymmetrically [6-7].

The process of Friction Spin welding is generally carried out by rubbing, preferably in rotational motion, the two parts surfaces in-coordination against each other [8]. The two plastic parts to be joined using friction spin welding are gripped separately in a rotatable fixture and corresponding mating stationery fixture respectively. The rotary fixture gives rotation to the one part and at the same time presses the rotating part on to the stationery part. The material at the interface is heated up due to frictional heat and become semi-fluid with the increase in temperature. Interface film and the melt flows out at the joint interface to form the weld bead, finally the rotation of the parts is stopped, the joined parts are allowed to cool and solidify under pressure condition for some time. Thereafter, the welded assembly is removed. The aforesaid process is usually carried out using a modified drill press where the rotary fixture is mounted upon the drill machine spindle and pressure is applied by pressing...
the lever manually. The aforesaid modified drill press is prone to producing inconsistent weld joints due to manual operation and require skilled operator. Alternative is to import from abroad spin welding machines which are very costly. Therefore, it was desirable to undertake the present work to indigenously develop a spin welding machine equipped with advanced process controls. It was anticipated that custom built friction spin welding machine with advanced controls offer numerous benefits in terms of consistent weld characteristics and much lower machine cost than the available alternatives. The present work is in that direction to fulfill the aforesaid gap by way of design and development of an indigenous machine and is an important showcase of possibilities of self-reliance with respect to special purpose machine tools in domestic industries.

2. Machine Concept Design

2.1. Need Analysis and Concept Design Generation

The architecture of the machine will enable it to receive fixtures (rotary and fixed) for affixing the different thermoplastic parts, which will be required to be joined together. These fixed and rotary fixtures should be located in axial alignment with each other. The rotatable fixture should be mounted on the spindle which should be part of spindle housing assembly. Spindle housing assembly should be capable of axial linear motion towards and away from the fixed fixture with adjustable pressure through human machine interface (HMI). The fixed fixture would be mounted on the fixed machine bed. For the axially aligned linear motion of spindle housing assembly it requires to be mounted on to a column through a guiding mechanism for enabling the smooth and constrained linear motion during spin welding operation. Rotary motion of rotatable fixture will be adjustable in terms of parameters such as rotations per minute, time of rotation etc. through HMI. The sketch of the proposed concept is depicted in figure 1.

The machine shall have easily accessible operating interface and control system. The aforesaid basic concept and requirements are further developed, explored, and analyzed. The maximum distance (daylight) between fixed fixture and rotary fixture is ascertained here. It has to be more than the sum of total height of welded components, the insertion depth in the fixed fixture & the rotatable fixture along with a suitable separation gap. The target thermoplastic part is assumed to be of 250mm in length. The insertion depth of fixed part in fixed fixture is taken as 50 mm and its total length to be 100mm. The insertion depth of rotary part in rotatable fixture is 20 mm and rotatable fixture’s total length is to be 50mm. The separation gap of 150 mm is assumed for easy accessibility and manual hand part mounting and removal operations. Therefore, the daylight is taken to be 500mm as shown in figure 2.
The linear stroke of spindle housing assembly need to be ascertained. It will have to be more than sum of the insertion depth in the fixed fixture & rotatable fixture and suitable separation gap. The insertion depth of filter in fixed fixture is 50 mm and rotatable fixture is 20 mm and the separation gap of 150 mm. Therefore, to broaden the capability of machine to weld even smaller length filters, the maximum linear stroke of 250 mm is adopted for the machine as shown in figure 3.

![Figure 3. Linear Stroke of Spindle Assembly](image1.png)

The swing of rotation i.e., distance of center of rotation from the front most surface of column is determined from the maximum diameter of work piece to be welded along with the consideration for dimensions of fixtures required to hold the work pieces. It is assumed that the maximum work piece diameter which may be welded will be around 100mm. This value is kept on higher side considering that the target current work specification diameter of prevalent filter housings is generally 62 mm. Therefore, the swing of rotation is kept at 135 mm after considering the space requirement for other additional features discussed in the following part of this work and is shown in figure 4.

The linear motion of spindle housing assembly need to be sturdy and it should be able to withstand the forces during spin welding operation while resisting the deviation from linear path. Further, it is desirable to have negligible wear and tear between moving parts and to keep the path exactly linear over the considerable period of usage. Therefore, it is desirable to mount the spindle housing assembly on the standard linear guide blocks and rails mechanism. It is thought that the rails will be mounted on to the solid steel vertical column, which will be precision machined to receive them. Therefore, considering these requirements, two linear rails and four guide blocks will be employed as depicted in figure 5. The linear guide ways allow linear motion by utilizing re-circulating balls between the rail and block and thereby achieving high precision linear motion. Because of the restraining effect between guide and blocks this mechanism should be designed to take loads in both left-right and up-and-down directions. This should allow the linear motion in axial direction only and should be able to transfer the undesirable forces during the operation to the column. In that view, it is assumed to use standard linear guide blocks as the advantages of using this and rail mechanism far outweigh its cost and further it will result into simplification of machine structure design, enhancement of its functionality, reliability, negligible maintenance and reduction in down time in the possible eventuality of breakdown.
Figure 6 shows the rotary fixture required to be fitted upon the spindle of the machine which constitutes of spindle shaft mounted upon a set of two angular contact bearings and a radial bearing in spindle housing. It is assumed to use the duplex set of two angular contact ball bearings (7007C, NSK, Japan) in back to back (DB) arrangement because these are capable to withstand radial as well as axial loads upon the spindle shaft at high speeds. The radial bearing (6205ZZ, SKF) supports the overhang
of spindle shaft. The bearings are fastened upon spindle shafts by the precision lock nuts. The spindle will be fastened to spindle housing by way of a clamp plate. The clamp plate will house inside it grease seal to retain the grease within the bearings. Owning to servo motors definite advantage in terms of low inertia, ability to accelerate & decelerate faster, precise rotation, position & time control, a 2 kW, 3 phase servo motor with suitable driver is selected for the purpose of rotating spindle shaft.

In order to have precise motion transfer from servomotor to spindle shaft, a high-stiffness and low-inertia servomotor couplings is employed. These couplings are also flexible in the torsional direction, in the uneven directions, and in the shaft direction, and are totally free from backlash.

The parts to be welded will be easy to mount/clamp and remove from the fixtures. In order to facilitate it, a pneumatic clamp mechanism with a fixed and movable jaw is conceptualized for the long stationary part of filter housing. When the stationary part is placed inside the fixed fixture and upon the pressing of button on operator console, the movable jaw will clamp the stationary part’s upper portion firmly. The fixed fixture and clamping assembly is shown is figure 7. This assembly will be mounted on the machine bed.

Programmable logic controller (PLC) will control all the operations of various subsystems of machine. The vertical linear motion of spindle is provided by employing double acting pneumatic cylinder driven by air as shown in figure 8. The requirement of variable thrust force required during spin and during cooling will be controlled by employing a variable pressure control valve operated through PLC which is commonly known as proportional pressure switch. It will deliver the air with required pressure to pneumatic cylinder and cause the required thrust during different phases of welding process. The air to be supplied to the pneumatic components has to be filtered, lubricated and regulated; therefore, a standard filter-lubricator-regulator (FRL) is selected to be installed on the side of column of machine.

The machine will be erected upon a steel frame table of suitable height so that operator can comfortably operate it while sitting in front of it on a chair. The steel frame table will have heavy duty castor wheels to enable the movement of machine when required. This compete assembled view of the machine is shown in figure 8.
2.2. Machine Control System Design
The control frame work of spin welding machine follows well defined pathways for flow of information and commands in likewise fashion for the proper functioning of different systems such as electromechanical, electronic, pneumatic and mechanical, which are required to function in particular manner and sequence to give the desired performance. The machine control flow diagram shown in the figure 9 elaborates the aforesaid flow of information.

The machine will have two control panels, one housing the PLC & HMI and another for Servo Driver will be located on each side of the machine column. The operator console with buttons for operating the machine will be located in the front of machine bed for easy access by the operator. In order to have the control systems function properly and to avoid the pitfalls of architecture mismatch between the communicating control systems the PLC, HMI and Servo Motor and Driver are kept of the same manufacturer supplier. The complete pneumatic component connections and requisite circuit diagram is shown in figure 10.

3. Final Assembled Machine and Manufactured Components
A fully functional prototype of Spin welding machine with advanced control system is developed based upon the above design parameters. Figure 11 shows the final fully assembled and fully functional Spin welding machine. The total weight of the machine is about 250 kgs. The machine is a table top model and can easily be rolled to any point using the rollers provided to the table. The cost incurred to manufacture the machine is about 4.5 lac. The total cost of the machine if manufactured in the bulk and with reasonable profit may be around 5 lac which is around 1/3rd the total cost of the
imported machinery from any reputed manufacturer. But as detailed earlier the manufactured machine is robust and is capable of functioning in the Indian conditions effectively. The machine is functioning satisfactorily. At present the manufactured Spin welding machine is used for the manufacturing of water filter cartridges for residential water purifiers at Hisar in Haryana. The different assemblies manufactured using the Spin welding machine using thermoplastic material are shown in figure 12. The machine is capable of controlling typical weld parameters viz. spin pressure, cooling pressure, rotation velocity, rotation time. The final collapse reading of weld joints obtained are within close limits depicting the high degree of consistency achieved in the process.

4. Conclusions
The following conclusions are drawn from the present study:
1. A newly indigenous Spin welding machine is designed and developed effectively. The machine is robust and capable of performing a wide range of spin weld joints.
2. The cost of the machine is about 1/3rd in comparison to the similar imported machinery. The machine is suitable to Indian conditions and can easily be maneuvered to any desired location.
3. The availability of such reliable spin welding machine with advanced controls to Indian manufacturers will enhance the quality of their welded thermoplastic parts at economical cost. It will further allow the product designers to leverage the technology and design innovative thermoplastic assemblies incorporating spin welding operation.
Figure 10. Pneumatic Component Connections Circuit Diagram
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