1 DESCRIPTION OF WELDING LOCATIONS, HARDWARE AND WELDING PROCESS

In this chapter, details regarding the spot welding location on the clip surface, the hardware developed for robot-based sequential ultrasonic welding and the welding process steps are provided.

1.1 SPOT WELDING LOCATION ON THE CLIP

In this section, the spot weld locations to join the clips to the skin and stringer, as well as the clips to the frames are shown. Keeping in mind the available weld area at each clip welding interface, the geometry of sonotrode used for welding was fixed to a cylindrical titanium sonotrode with a flat circular contact surface of 20mm-diameter. The sonotrode shall be used for spot welding both clip interfaces i.e. clip-skin-stringer and clip-frame at 8 distinct spots as can be visualized in figure 1.

The average welded area at each spot weld location is 220 mm^2. In order to minimize edge heating effects and potential damage to the clips, the welded area was kept lower than the interface area. The distance from the edge of the sonotrode to the edge of the welded spot is 2.5 mm for the clip-to-skin joints as seen in Figure 1 (left). At the interface of each spot welding location, the energy director is molded, concentric with the intended circular spot location and with a diameter of 23 mm.

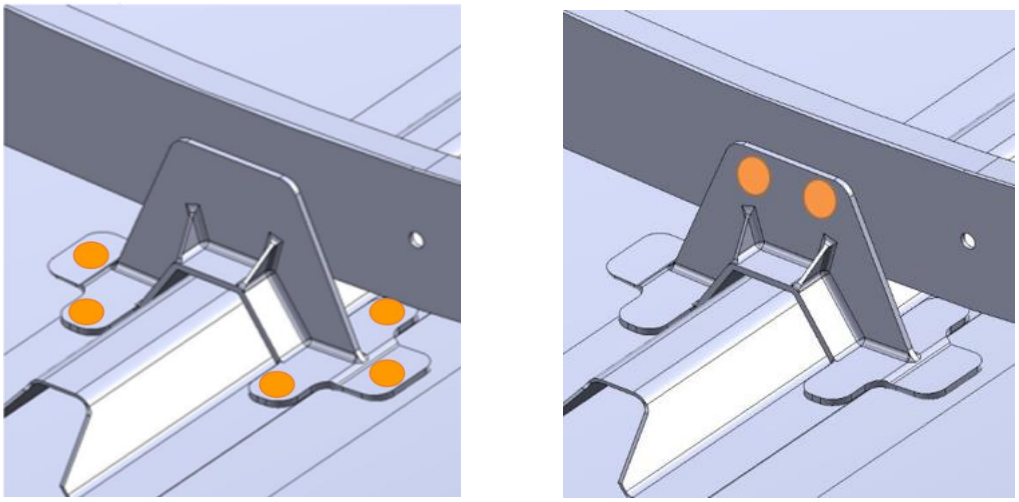

Figure 1: Weld spot locations on the frame clips. Clip-skin joint location (left) and Clip-frame joint location (right)

1.2 WELDING HARDWARE

This section describes the welding hardware developed at SAM|XL and TU Delft for welding the two configurations of spot welds i.e. Clip-to-skin and Clip-to-frame. For a modular set-up, the end-effector comprises of an extension beam that can be used to mount either of the two tools developed for each of the welding configurations. The ultrasonic generator is mounted on the beam and can be used for powering either of the tools depending on weld configuration/assembly step. Finally, the beam also houses a cabinet containing the control electronics and pressure regulator.

1.2.1 CLIP-TO-SKIN (CTS)

The tool designed for the clip-to-skin welding process is mounted to the front of the welding beam, as seen in Figure 2**.** The assembly consists of a Rinco Ultrasonics SPA20 welding machine with an AGM20 ultrasonic generator. The welding machine is mounted onto the extension beam together with a clamping tool, as described in the previous section. A clamping tool which can be independently actuated is used to restrain movement of the clips during ultrasonic welding.

Figure 2: Clip-to-skin welding tool

1.2.2 CLIP-TO-FRAME (CTF)

The tool designed for the clip-to-frame welding process can be seen in Figure 3. The main difference between the two tools is that in the tool designed for clip-to-frame welding, due to the vertical orientation of the clip-to-frame joint and a lack of tooling to apply back pressure, the tool contains an integrated anvil. The tool is designed in a way that allows the anvil to be positioned at the flange side of the frame, in order to apply back pressure for welding. The tool schematic can be seen in Figure 3 (left). The CTF tool shares the same ultrasonic generator as the CTS tool. The actuation of the anvil as well as the ultrasonic stack along a linear rail is done by pneumatic air pressure. Unlike the CTF tool, the tool uses a compact pneumatic cylinder instead of a dedicated press. This is a new tool configuration for ultrasonic welding of composites and shall be tested and proven for the first time for application of USW on the MFFD.

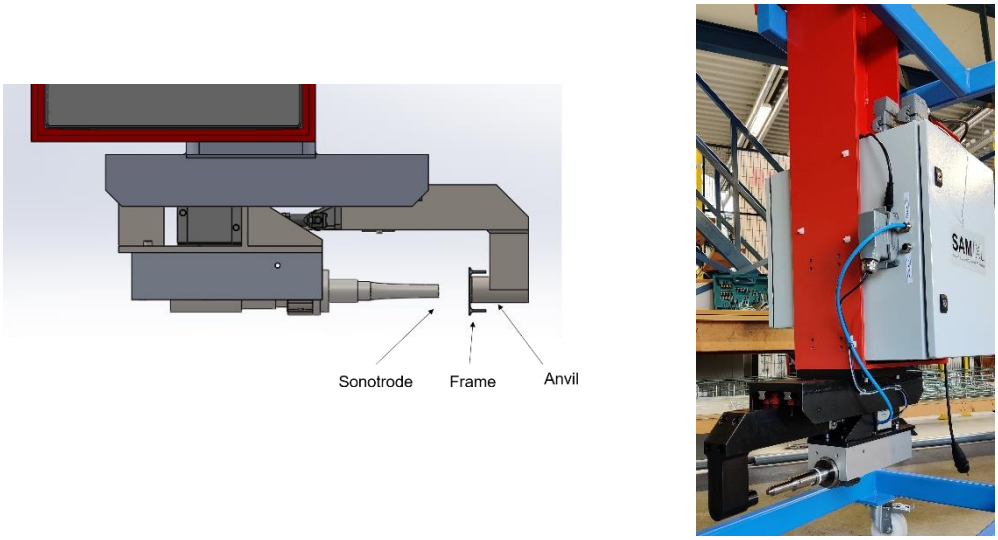

Figure 3: Clip-to-frame welding tool schematic (left) and assembled tool mounted on KUKA robot for testing (right)

1.3 WELDING PROCESS DETAILS

The welding process for each spot weld consists of a motion of the gantry robot, motion of the clamping tool and triggering of the welding process. Details about the motion of the gantry to position the sonotrode correctly are outside the scope of this document. In this section, first the reasoning behind the welding sequence for each clip is explained, followed by a description of the clip clamping concept and detailing the steps of the welding process.

1.3.1 SPOT WELDING SEQUENCE ON EACH CLIP

The welding sequence for spot welding the clips was defined based on specific requirements and challenges that pertain to the design of the clips and accessibility of the end-effector for welding each spot. The clip-to-skin joint welding of 6 spots is a different process step to the clip-to-frame joint with 2 spots. The welding sequence and location of each spot weld is illustrated by corresponding numbers in Figure 2 and Figure 3, respectively.

For the clip-to-skin joint, it was decided to weld the two outer feet of the clip to attach the clip to the skin (location 1 and 2), followed by welding the remaining 4 spots to attach the clip to the stringer feet (location 3,4,5 and 6). The primary reason of doing this is to mitigate the risk of misalignment of interface between the clip outer feet (location 1 and 2) and the skin which is likely to happen if the skin-stringer spot welds are done first, due to the uneven surface present on the stringer interface due to conduction welding. The secondary reason for this welding sequence is to allow the use of a clamping tool that restricts movement of the clip in-plane during the welding process. The welding sequence is such that it is only required to clamp the first two spots. After the first two spots are welded, the clamp can be retracted for the remaining welds for each clip. Further details regarding the clamping concept are provided in the next section.

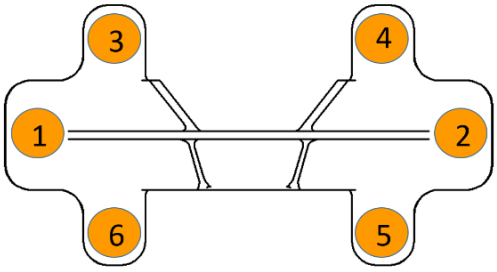

Figure 4: Sequential spot welding sequence for clip-skin-stringer joint

For the clip-to-frame joint, the welding sequence does not influence the process. To maintain a standardized process for robot programming, the sequence is defined from left to right, as can be seen illustrated in Figure 3.

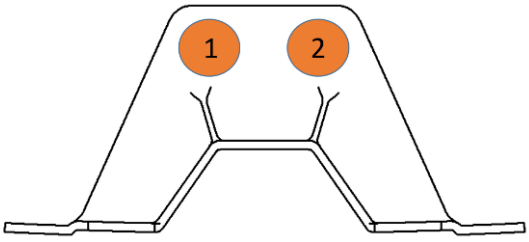

Figure 5: Sequential spot welding location and sequence for clip-frame joint

1.4 WELDING SEQUENCE OF CLIPS IN THE DEMONSTRATOR

The welding sequence of clip to skin joining is fixed so the clips shall be welded to the skin, one row at a time along the inner circumference of the fuselage shell, in order to ensure the alignment of clips with respect to each frame surface.

The clip numbering is based on the frame number (1-12) as the prime identifier, with the stringer number (1-20) appended. The clip nomenclature is defined as <data type_stringer number_weld number>. The weld sequence for the clip-to-skin integration is pre-defined due to requirement of the reachability of the tool and sequential installation of the frames to allow tool reachability. **Note:** Due to the manufacturing requirement not all stringers contain a welded clip. Hence welding data is not recorded all stringers in the sequence of 1-20. The data recorded for each weld spot is stored in two files each with a recording rate of “1kHz” and “100Hz”.

1kHz file contains a time stamp (ms), pressure (bar) and vertical displacement data (mm) captured during the welding process for a spot weld which was recorded at 1kHz.

The conversion factor for pressure in bar to force in N is 266.667. i.e. 1 bar = 266.67 N.

100Hz file contains a time stamp (ms) and power data (W) captured from the ultrasonic signal generator.

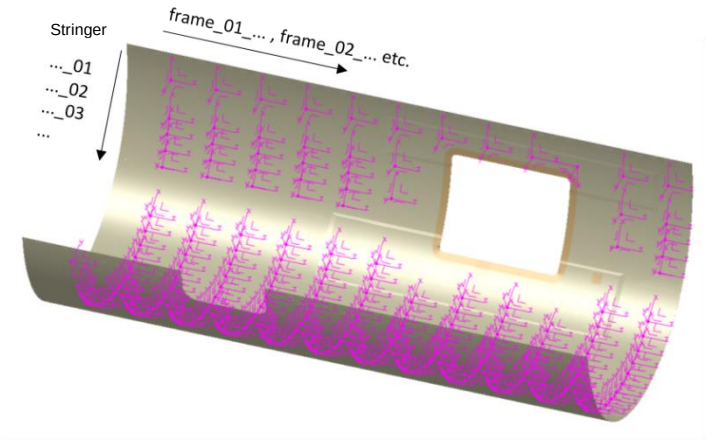

Figure 6:Stringer, frame and clip nomenclature in the lower shell demonstrator