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Friction Stir Welding Development

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Introduction

The research of this summer was a continuation of work started during the previous summer faculty fellowship period. The Friction Stir Welding process (FSW) patented by The Welding Institute (TWI), in Great Britain, has become a popular topic at the Marshall Space Flight Center over the past year. Last year it was considered a novel approach to welding but few people took it very seriously as a near term solution. However, due to continued problems with cracks in the new aluminum-lithium space shuttle external tank (ET), the friction stir process is being mobilized at full speed in an effort to mature this process for the potential manufacture of flight hardware. It is now the goal of NASA and Lockheed-Martin Corporation (LMC) to demonstrate a full-scale friction stir welding system capable of welding ET size barrel sections.

The objectives this summer were:

- Implementation and validation of the rotating dynamometer on the MSFC FSW system.
- Collection of data for FSW process modeling efforts.
- Specification development for FSW implementation on the vertical weld tool.
- Controls and user interface development for the adjustable pin tool.
- Development of an instrumentation system for the planishing process.

Implementation & validation of the rotating dynamometer

The two primary parameters in the friction stir process are rotational speed and plunge force. The rotation speed is set and monitored by the CNC milling machine used to perform the weld. The plunge force is not a typical milling parameter and so it not available on typical mills. The plunge force is a critical parameter in defining design specifications for a friction stir welding system and is likely to the most important parameter in process control of the friction stir welding process.

A major accomplishment of the previous summer was the calibration of motor currents to force on the MSFC FSW system. It is a straight forward process to calculate the plunge force applied from the motor current and the parameters for the motor and mechanical gearing system. Our approach was to monitor the current required to drive the motors controlling each axis of the mill. We then used calibrated load cells to measure the force applied and the corresponding motor currents. From this experiment we obtained scale factors to convert motor currents to pounds of force.

There were many skeptics of the validity of this approach or the quality of the resulting data. A precision rotational dynamometer was investigated and recommended for procurement by NASA. The selected instrument was a multiaxis dynamometer built by the Kistler Corporation. The Kistler dynamometer was designed to measure cutting forces experienced by a milling machine and appeared to be well suited to the MSFC friction stir welding system. The dynamometer is inserted into the spindle of the mill with the FSW tool attached on the end. The dynamometer can measure the three forces x,y,z and the torque required to turn the tool. These signals are generated in the dynamometer and telemetered magnetically, without the need for slip rings, to a signal conditioning box. A robust +/- 10volt signal is produced by the signal conditioner for connection to a computer data acquisition system. Figure 1. illustrates the FSW system at MSFC in building 4711. The results from the dynamometer verified that the method of calibrated motor currents is a completely valid and economical method for measuring loads.

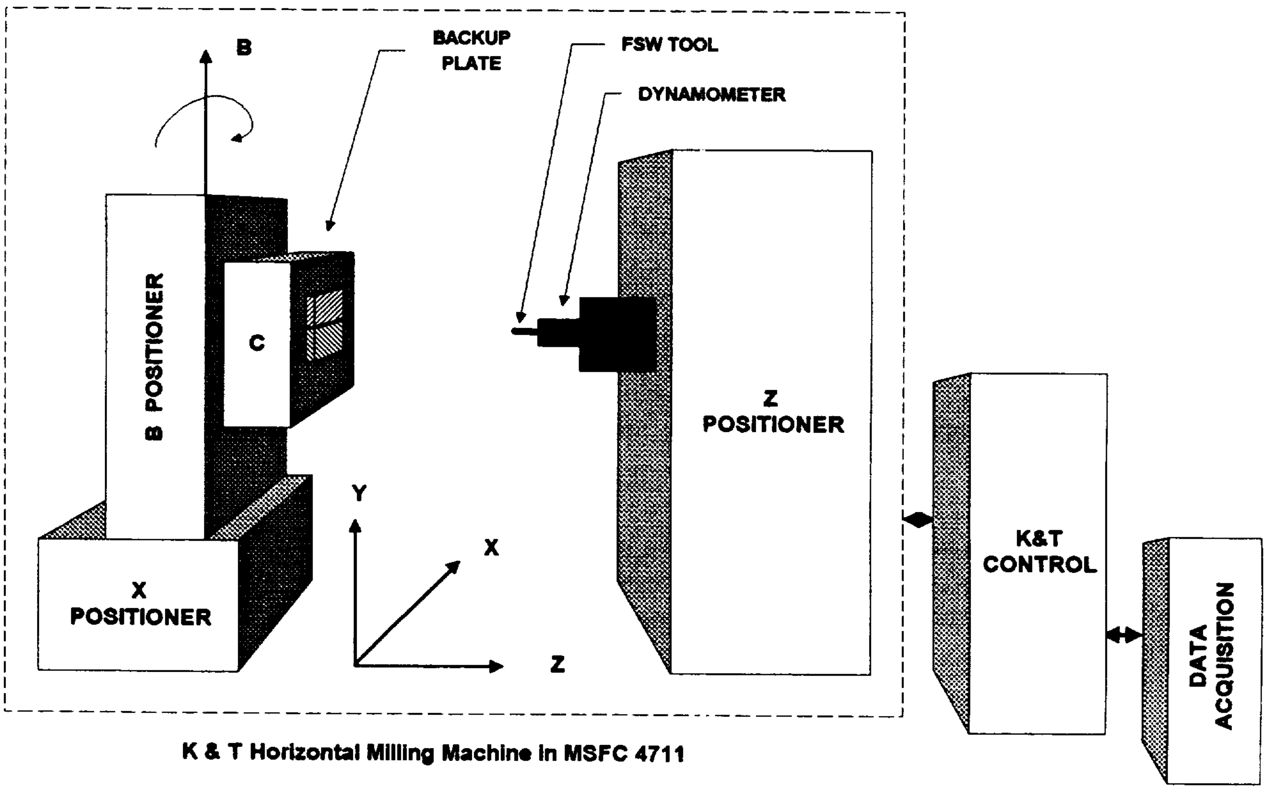

Figure 1. Friction Stir Welding System at MSFC.

Collection of data for FSW process modeling

The dynamometer provides data for the three forces (X,Y,Z) and the torque (Mz) required to turn the tool. The Z force has been the parameter of most concern due to its magnitude and direct effect on weld quality. The primary goal of force measurement has been to determine structural and mechanical design requirements for a friction stir welding system. The Z force and torque establish benchmarks for structural design and horsepower and load requirements for machine design. The X and Y forces have been of less concern due to their smaller values and relatively flat response. However, the X and Y forces were of great interest to those developing a scientific model for the friction stir process.

Typical welds made on the MSFC system last approximately 3 minutes and it was determined that a sampling rate of 2Hz was sufficient to capture the significant information of all loads using calibrated motor currents as well as the Z load from the dynamometer. Due to the X and Y axis being relative to the dynamometer, these axis rotate as the dynamometer rotates so that a continuous X or Y load appears as a sinusoidal output voltage. The frequency of the sinusoid is proportional to the rotational speed of the spindle and it was determined that a sample rate of 50Hz was sufficient to capture this information. Although this was not a technical challenge for a modern data acquisition system, the significantly increased volume of data produced resulted in concerns of storage and data handling.

Specification development for FSW implementation on the vertical weld tool

Due to continued problems with cracks in the super light weight external tank project, NASA and Lockheed-Martin Corporation (builder of the external tank) reached the decision to aggressively investigate the applicability of the friction stir process to the external tank. The plan developed was to design, build and operate a full scale friction stir welding system utilizing the existing vertical weld fixture in building 4705. I was involved in the development of the specification for vertical weld tool system due to my experience with the friction stir process load and torque requirements and the adjustable pin tool under development at MSFC.

Controls and user interface development for the adjustable pin tool

The adjustable pin tool prototype was developed at MSFC during the 1996 summer faculty fellowship period. It was initially developed to address the issues of weld closeout but its application to welding tapered thicknesses was understood. My involvement in the adjustable pin tool has been the design and implementation of the motor and sensor electronics and associated control hardware and software. This included the specification of equipment and software. I expect to have continued involvement in the adjustable pin tool through integration and operation on the new vertical weld tool system.

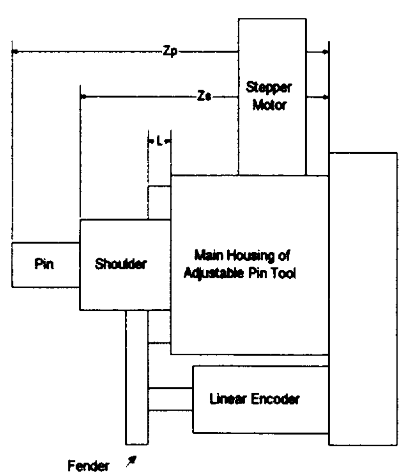

Figure 2. Adjustable Pin Tool (APT)

Development of an instrumentation system for the planishing process

The planishing process has been used to relieve the residual stresses introduced into a plasma welded joint due to the repair process. After the initial weld is performed an extensive inspection process is used to locate weld defects. The defect is then ground out of the weld and a repair weld is inserted. The are of the repair is then planished using a pneumatic hammer and steel bucking bar. Through planishing the distortion from the repair is literally hammered out.

The planishing process has been successfully used to increase weld strength and reduce the occurrence of cracking formerly associated with repair welds. In the past there has been very little science used to specify how the process is to be applied or exactly what is happening during the planishing process. An instrumentation system was developed to measure the planishing forces. The system consists of two quartz load washers and two accelerometers, one each for the planishing gun and bucking bar.

The system will initially be used to collect data to characterize the planishing process. Eventually it could be part of a planishing training system or real-time planishing monitor.

Summary and Conclusion

The Friction Stir Welding process is sure to become a standard joining process for aluminum alloys, especially in the aerospace industry. The projects started this summer will lead to a full scale friction stir welding system that is expected to produce a friction stir welded shuttle external tank type barrel section. The success of this could lead to the implementation of the friction stir process for manufacturing future shuttle external tanks.

Acknowledgment

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