FSW-Tech

Friction Stir Welding European Qualifications

CU11 – FSW System Implementation

FSW Engineer

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11. Joint Definition

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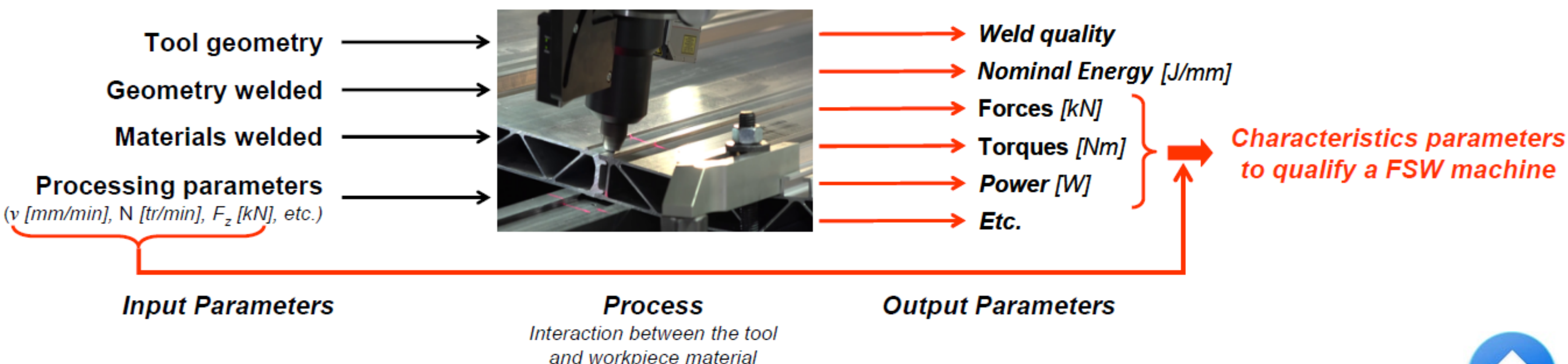
11.1 FSW Equipment

Three kinds of machines are reported in literature as viable to perform FSW. These machines are:

- Conventional machine tools such as milling machines;
- Dedicated FSW machines or custom-built machines;
- Industrial robots.



Presentation of the input and parameters related to a FSW operation

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11.1.1 Conventional FSW machines

- The process of FSW is similar in terms of equipment principle of operation like others manufacturing processes such as machining, deburring, grinding or drilling. Thus, a **conventional machine**, such as a milling machine, can be used to perform FSW of thin aluminium alloys parts.
- **The loads involved in FSW are higher than the loads generated in the milling process**.
- For this reason, conventional machine tools have to be strengthened in order to increase their **load** and **stiffness capabilities**.

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11.1.2 Dedicated FSW machines

- Dedicated FSW machines tend to have the **highest load capability**, **stiffness**, **accuracy** and availability [23].
- Typically, dedicated FSW machines are relatively expensive and **their cost increases with the flexibility capability**.
- The use of dedicated FSW machines is recommended for high series weld production of thick/thin parts in applications where:
  - high stiffness is required;
  - single or multi-axis applications;
  - long weld paths.

Dedicated FSW machines

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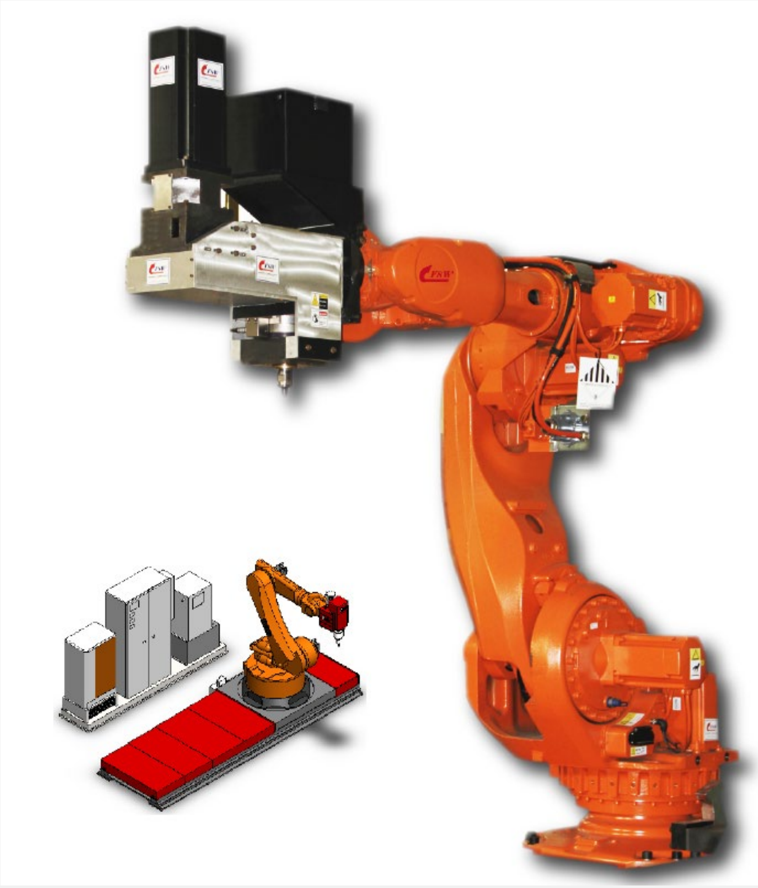
11.1.3 Industrial Robots



FSW Equipment and Control Systems [12]

Classification

General Robotic FSW System

Robotic FSSW System

Robotic Bobbin FSW System

Robotic Floating Bobbin FSW System

Robotic Stationary Shoulder FSW System

- Higher automatic welding processing
- More complex structure, e.g. 2D, 3D
- Multi-control models, e.g. pressure, position and torsion controlling model
- Higher quality with lower deformation joint
- More stability

Robotic FSW system with two welding stations for simultaneous welding and loading/unloading of components

A) HMI / process & system control
B) FSW welding head with FSW tool
C) Welding station 1
D) Welding station 2
E) Industrial robot
F) Safety housing with automatic roller shutters

Welding parameters FSW robot system

Welding speed .... up to 2,000 mm/min
Welding depth .... up to 10 mm
Process forces axial .... up to 10 kN
Process forces radial .... up to 5 kN
Spindle rotation .... up to 10,000 min^{-1}

The robotic-based solutions are available in two basic categories [23]:

- Articulated arm robots
- Parallel-kinematic robots

Articulated arm robots present **high repeatability** and **flexibility** but **low accuracy** that worsens when they are subjected to high loads.

Comparing articulated robots to dedicated FSW machines, these robots display higher flexibility and decision-making capability besides the fact that they are remarkably lower in cost. However, these types of robots have relatively **low** stiffness and **moderate** load capability which limit their application.

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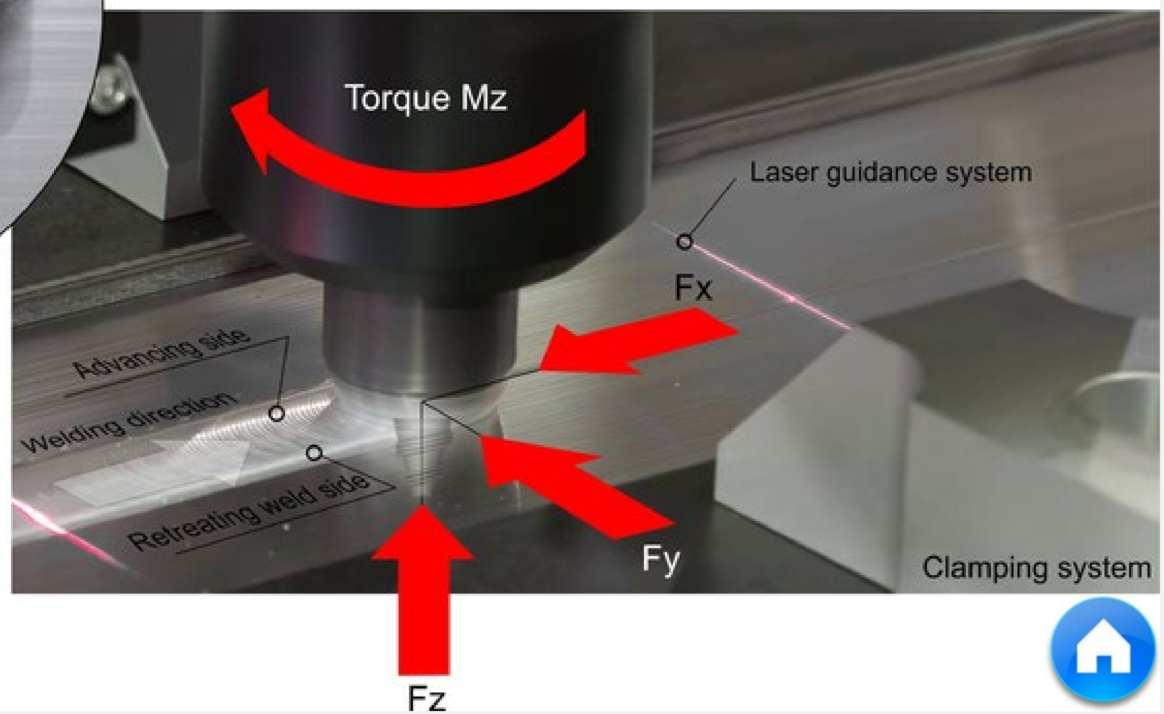
11.1.4 Equipment force capability

A challenging issue in FSW is to have a machine able to support the high loads generated during the welding process, which depends greatly on the material type and thickness of the work pieces.



The most **relevant loads** acting on a FSW machine:

1. the axial force (Fz),
2. the traverse force (Fx),
3. the side force (Fy),
4. the torque (Mz).

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Force capability

Axial force (Fz)	Side force (Fy)	Traverse force (Fx)	Torque (Mz)
Axial force is one of the main process parameters. It assure the friction between the FSW tool and the work pieces and also the forging pressure required in order to obtain a good weld formation. The heat produced in the FSW process depends directly on the axial force.	**The side force** (radial force) results due to the asymmetry of the FSW forces caused by the tool rotation. The advancing side is softer and thus, less resistant. This force is oriented from the retreating side towards to the advancing side of the weld.	**Traverse force** is produced by the material resistance to the tool movement along the joint line (it is opposite to the welding direction).	**Torque** is maintaining the friction force between the FSW tool and the work piece assuring the material stirring and nugget formation.

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11.1.5 Control System

- All machines are controlled using the latest of PLC technology (Programmer Logic Controller) and high accuracy drives. This allows the machine's axes position and speed to be controlled delicately and precise.
- The Z-axis control works in either on position or on set force control mode.
- The menu driven touch-screen HMI interface is designed specifically for FSW. It is the interface for setting up the process parameters, the welding path as well as the most common machine parameters. It also provides monitoring capabilities of the process parameters, alarms and system status.

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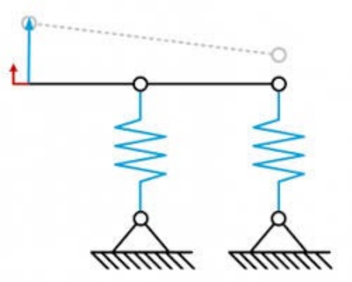
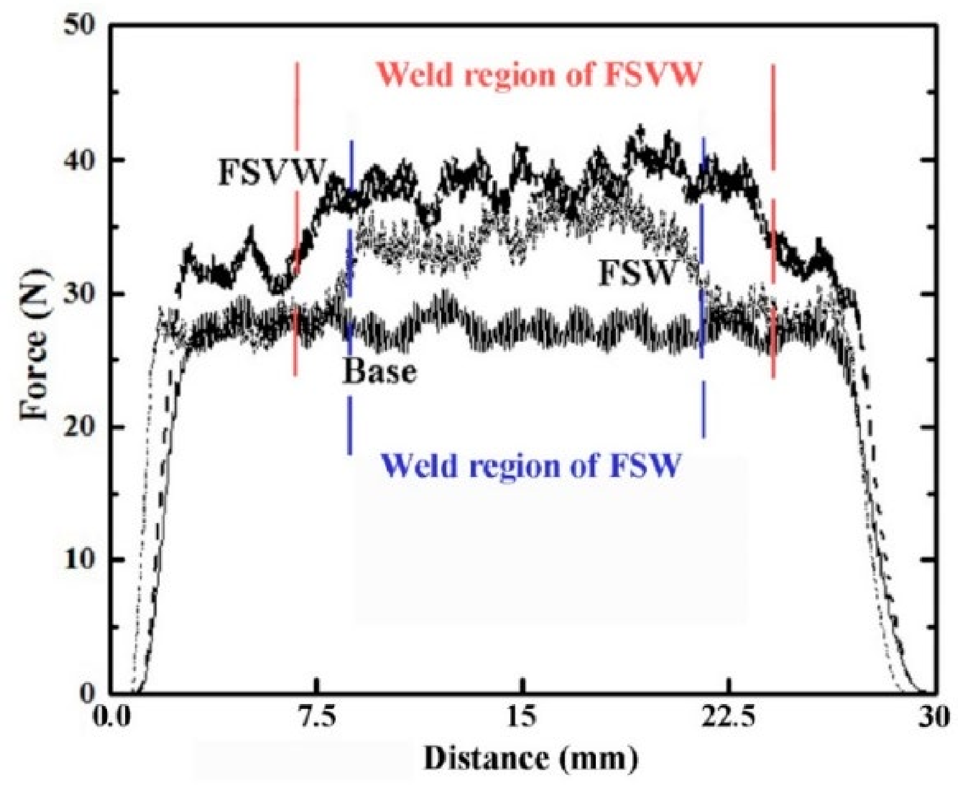
11.1.6 Stiffness and accuracy capability

This is the ability of FSW equipment to withstands loads **without undergoing deformation** or **deflexion**.

When a FSW machine presents **low stiffness** its FSW tool deviates from the desired welding path, **strongly affecting weld quality**.

Moreover, low stiff machines tend to cause **excessive vibration** which in turn can lead to FSW process instability.





11.1.7 Sensing capability

- Sensing consists on the **machine ability** to be aware of some **phenomena that are occurring in the weld joint**, i.e. values of **direct** and **indirect welding variables** involved in FSW process that reflect the evolution of the welding material and consequent welding formation.
- **direct welding variables** the welding parameters that some how can be actuated in a direct way (the **rotational** and **traverse speeds**, the **tilt angle** and the **external heat input**)
- **indirect variables** all those variables that cannot be actuated in a direct way, they depend on other variables. This group of variables is composed by the loads involved in the welding process (**axial force, traverse force, side force and torque**), the **temperature** reached in the welding area, the **stirred material flow** and the **stirred material mixture**.

11.1.8 Decision-making capability

Control methods can be implemented in the control system of the equipment in order to allow process self-adaptation.

The data provided from sensors (values of the direct and indirect variables) are used as **feedback** to the control system.

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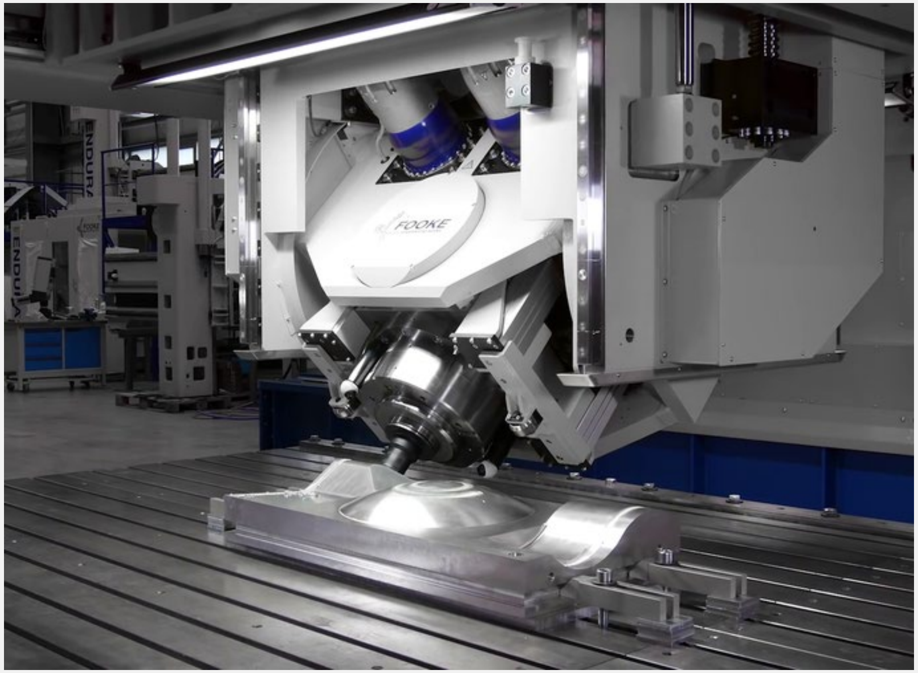
11.1.9 Flexibility capability

- The flexibility of a machine limits the **complexity** of a **welding path** (linear, curve) that can be performed.
- The number of axes (**degrees of freedom - DOF**) that a machine possesses usually establishes the flexibility of the machine.



- A three-dimensional (3D) welding path is the most demanding in flexibility. A **machine to perform the simplest 3D path must have at least five axes**. Many applications require multiple welds in different directions, which impose the required flexibility of the machine.

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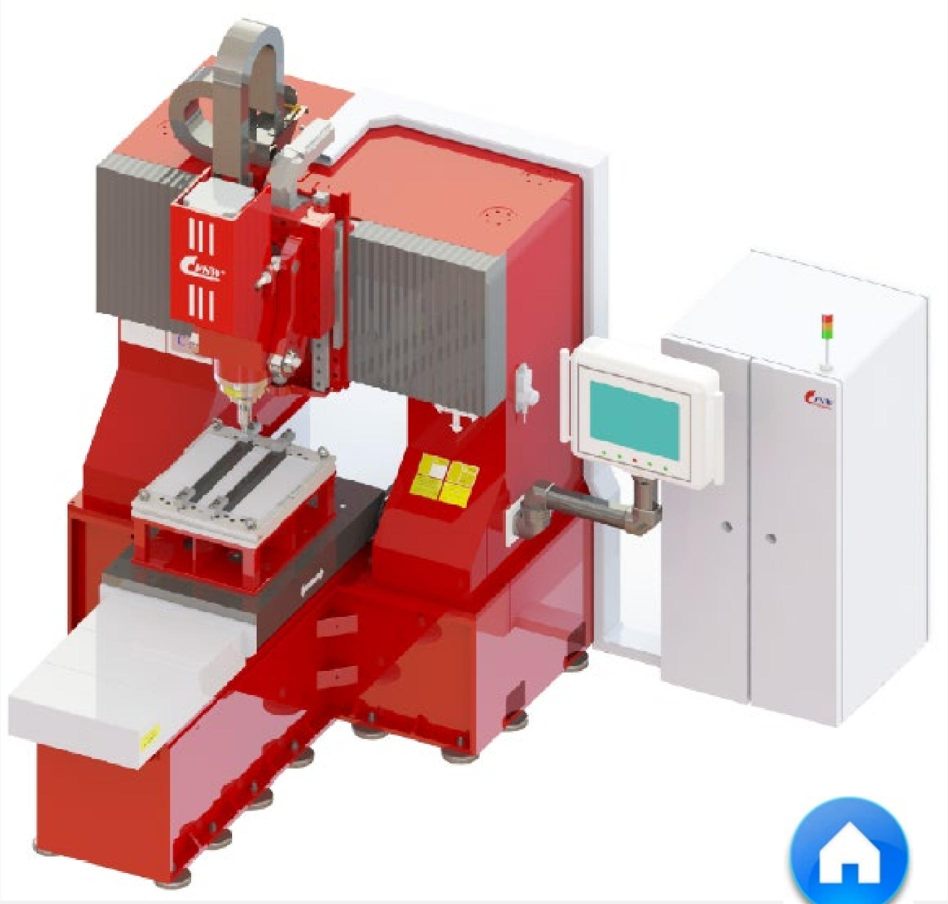
11.2 Equipment components

- Rigid framework
- Strong and fast motion components
- Advanced tool control system (CNC)
- 5 axis for 3D weld path
- Position & Control Force System
- System for recording & monitoring the welding parameters
- FSW heads with bobbin technology for welding thicker parts
- Laser seam tracking solutions
- Video system monitoring



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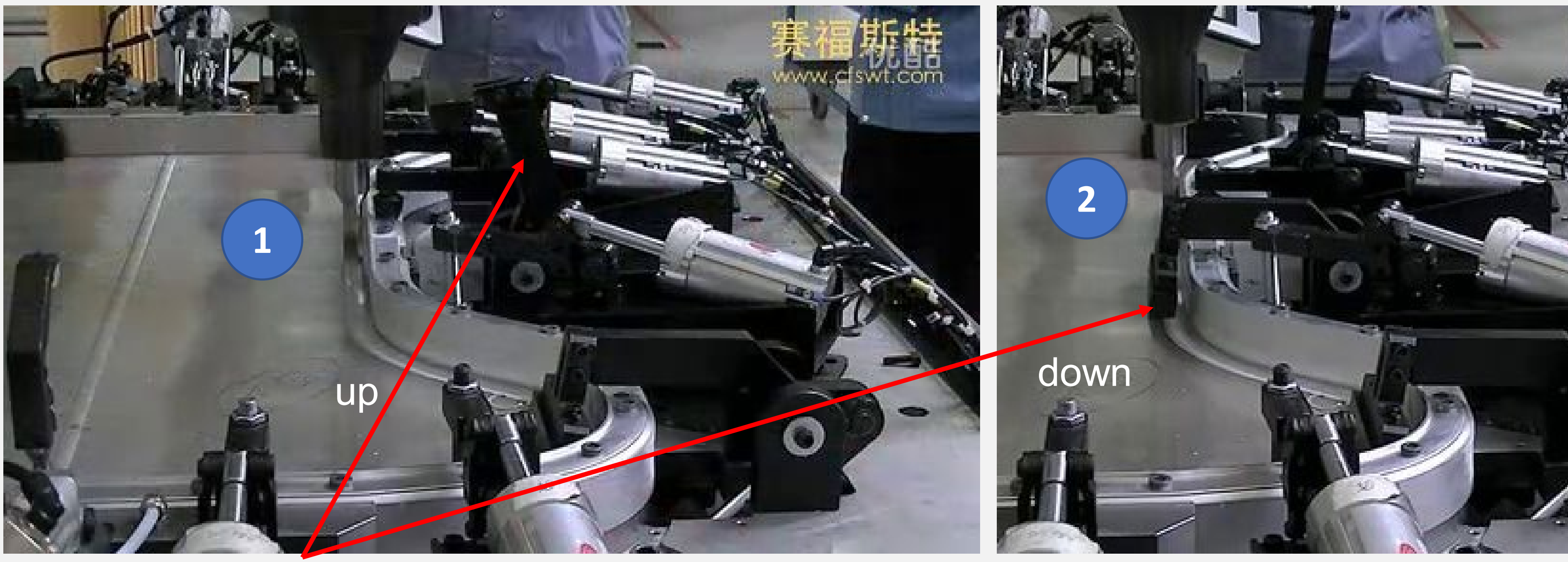
11.2 Clamping system



Advanced clamping systems can be individually controlled according to the tool position. The clamping shoes are lifted and lowered automatically based on the FSW tool position. It can be done using proximity sensors or by a code program.

Pneumatic action/control of the clamping system composed by multiple shoes that assure proper components fixture.

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11.2 Clamping system

Vacuum adsorbing backing plate

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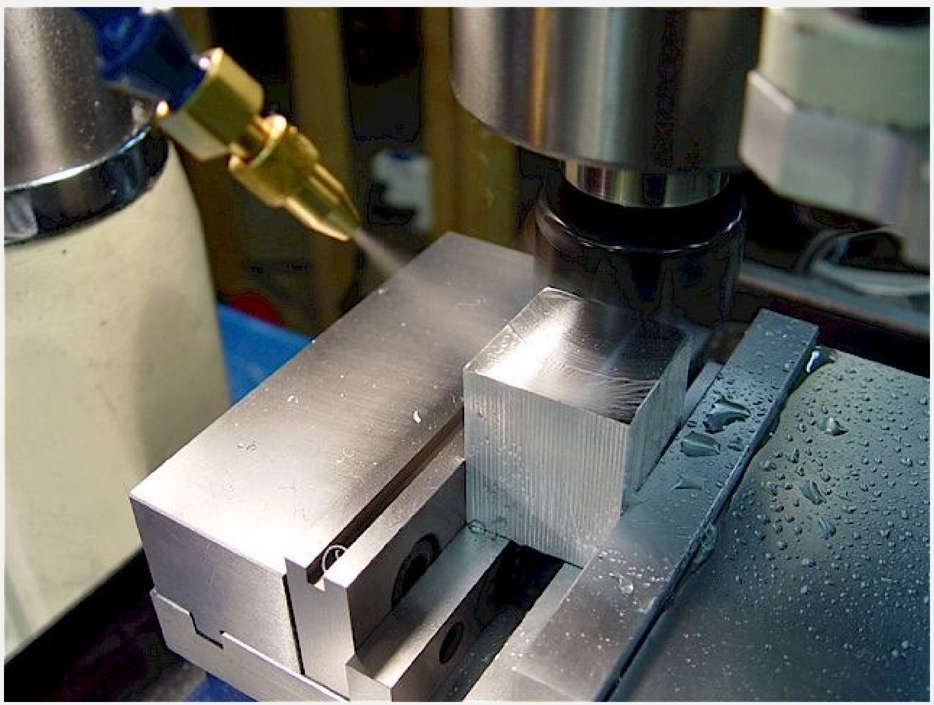
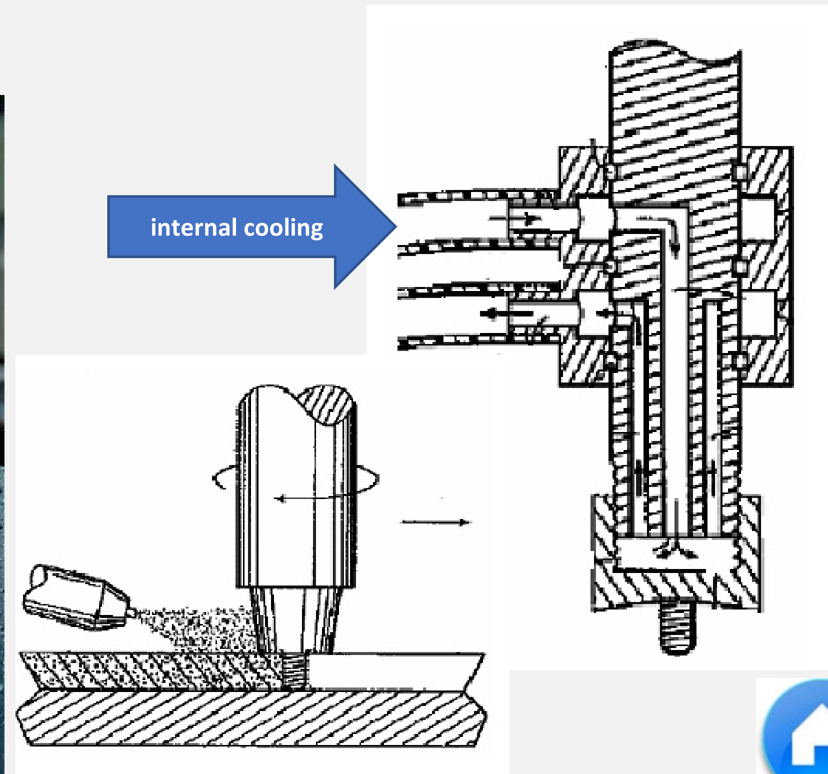
11.4 Cooling System

Gpm – gallon per minute
1 Gpm = 3.78 Liters per minute

- a coolant rate 0.01 Gpm for direct cooling
- a coolant rate 0.1 Gpm for internal cooling
- cool air or gas is sprayed in the fins





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11.4 Laser tracking system

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11.5 Production running costs

In term of the cost this issue depends on the **size** of FSW machine, if we consider a small robot that has a small table on which the specimens will be welded, the price could be around 100,000 Euro and if we discuss about large equipments the price can reach up to 3-4 million Euro.

Machines selection for FSW should consider:

- the workpiece size,
- the volume production,
- forces involved in the FSW,
- system stiffness,
- accuracy capability,
- sensing capability,
- decision-making capability,
- flexibility capability.

Bringing FSW to the production floor, however, is neither a simple nor risk-free endeavor. Successfully implementing this rapidly evolving process requires:

- considerable process expertise,
- **a sound development plan**,
- **reliable,** technologically advanced equipment.

Carefully weighing such factors as **budgetary limitations, time constraints**, and your organization's level of FSW **process development expertise**.

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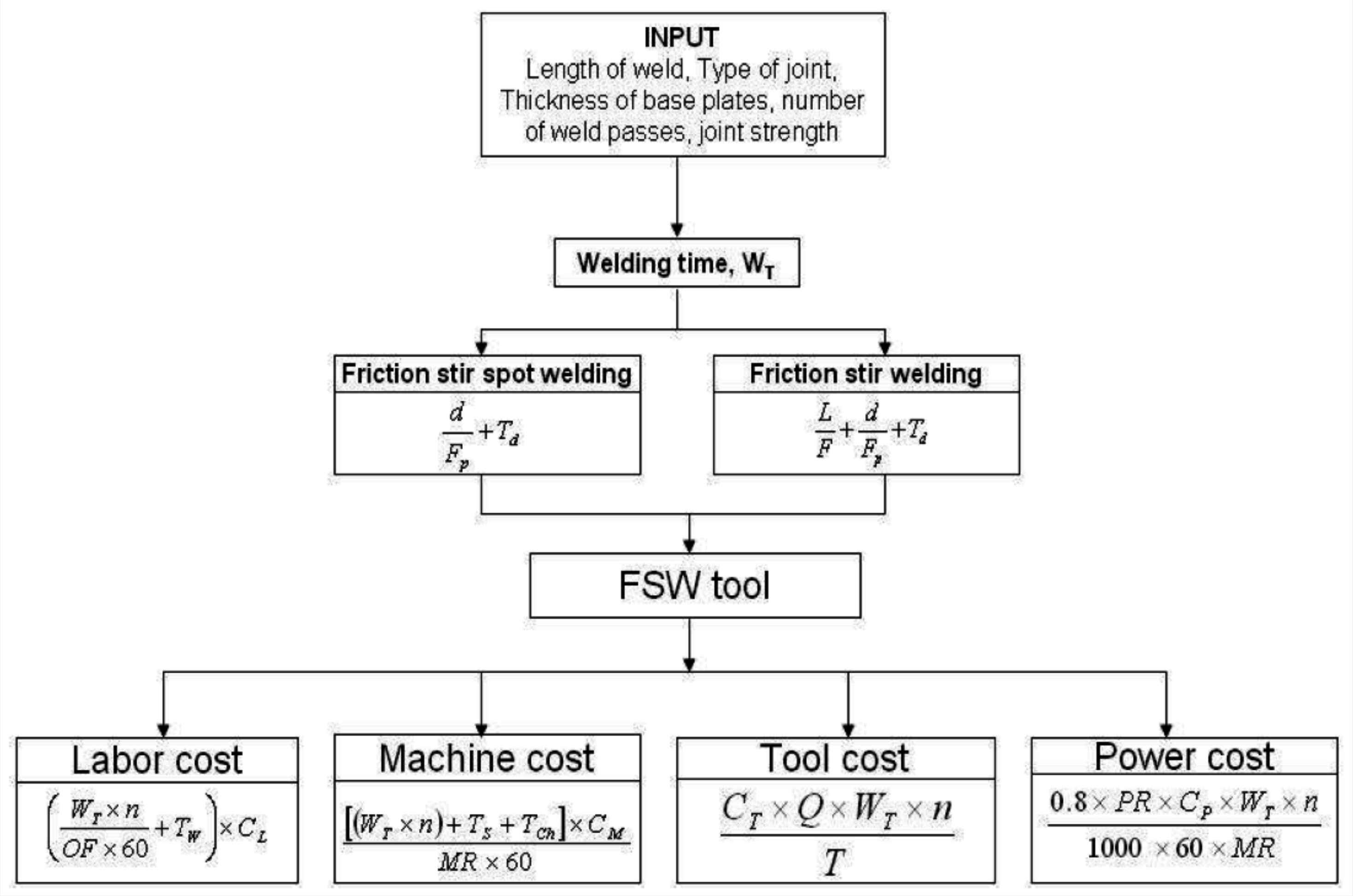
11.5 Production running costs



Flow and various costs in the FSW cost model [15]

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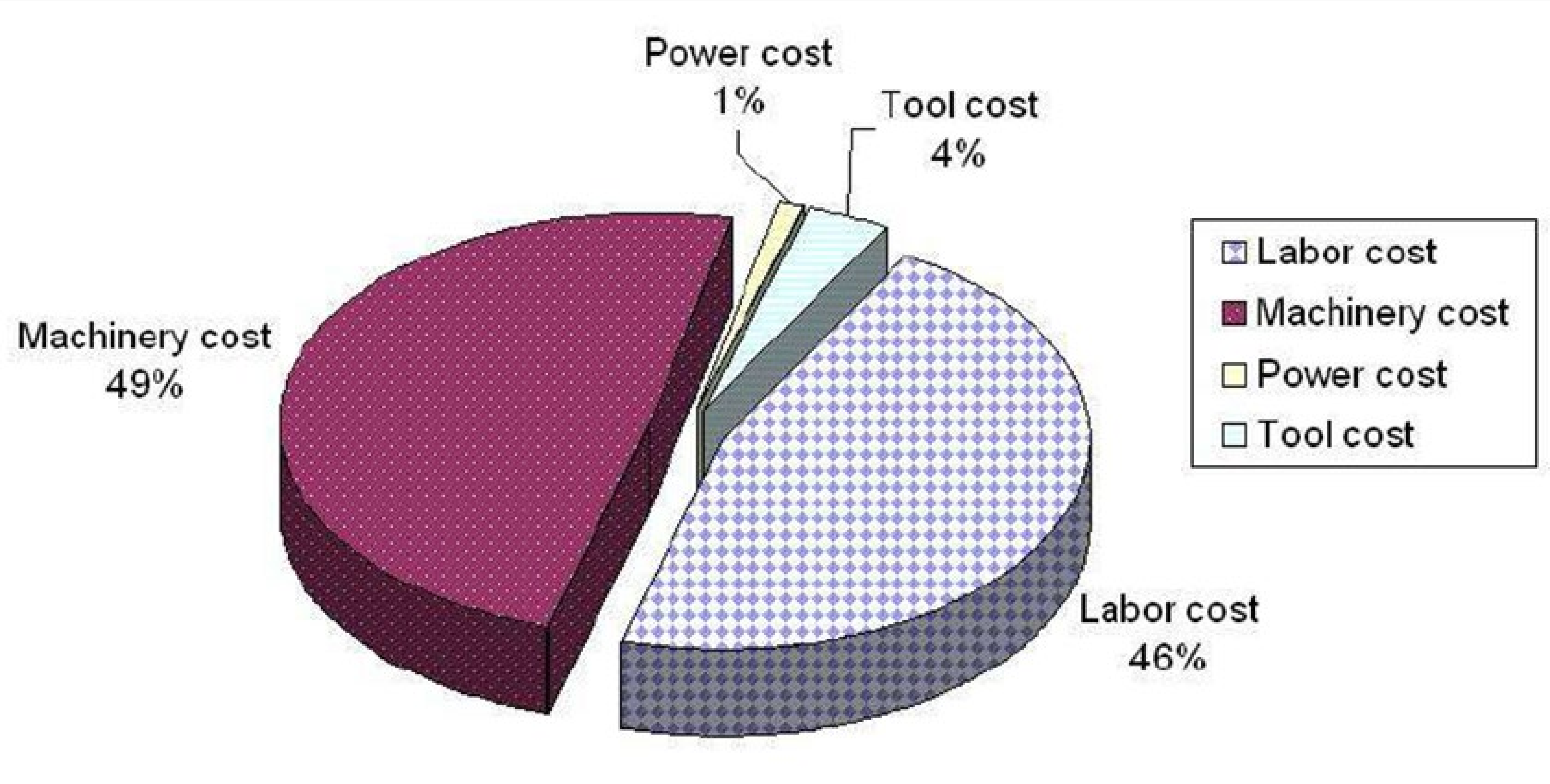

Distribution of cost components of FSW process [15].

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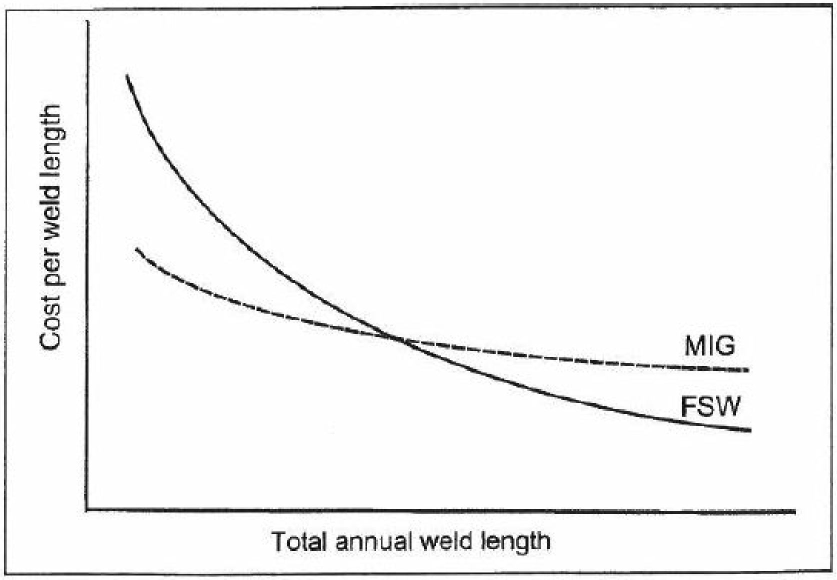

Fig. 3. Schematic representation of FSW and MIG welding costs per length vs. total annual production.

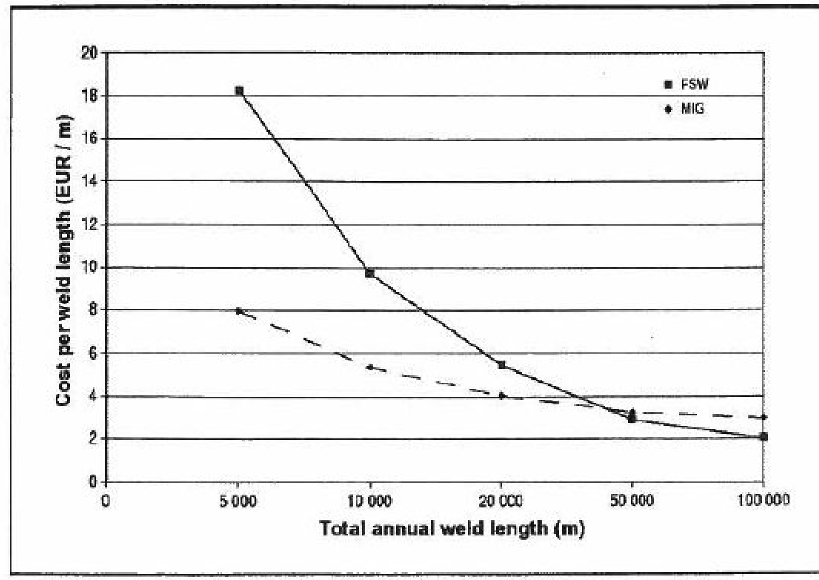

Fig. 4. FSW and MIG welding costs for different annual production amounts. Other parameters as in Table 4.

[10] Cost Comparison of FSW and MIG Welded Aluminium Panels

FSW vs. MIG – Process costs [10]

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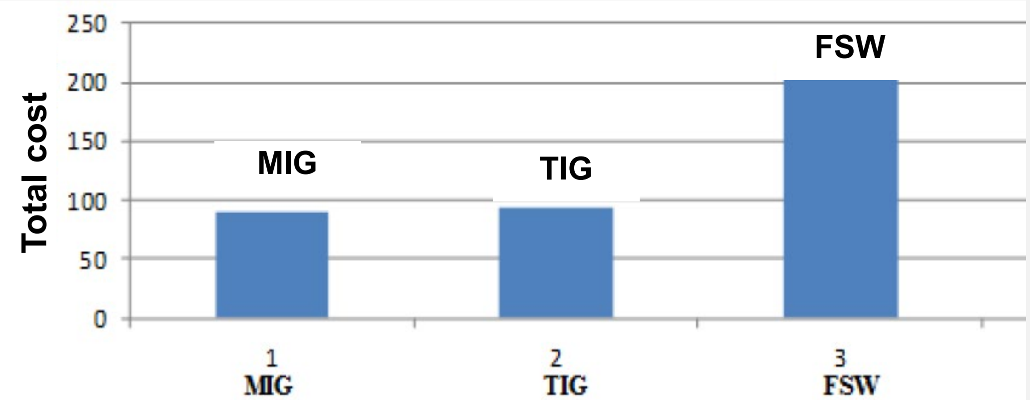
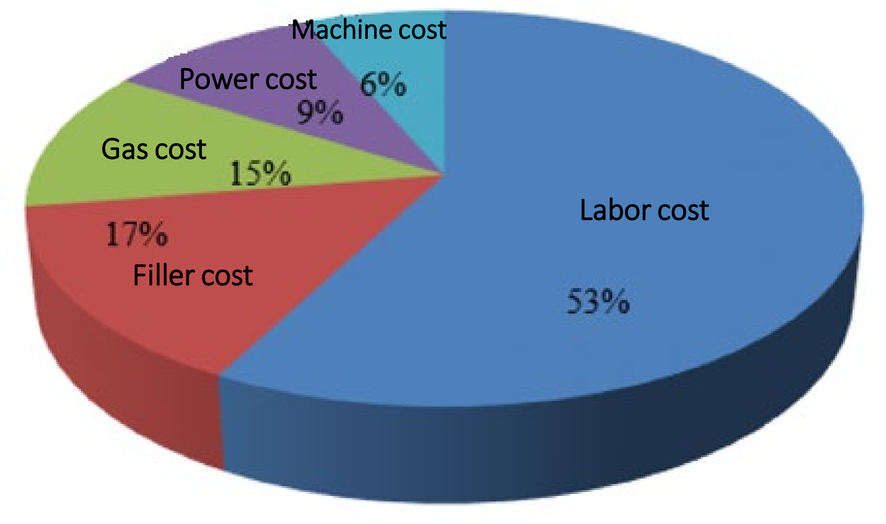
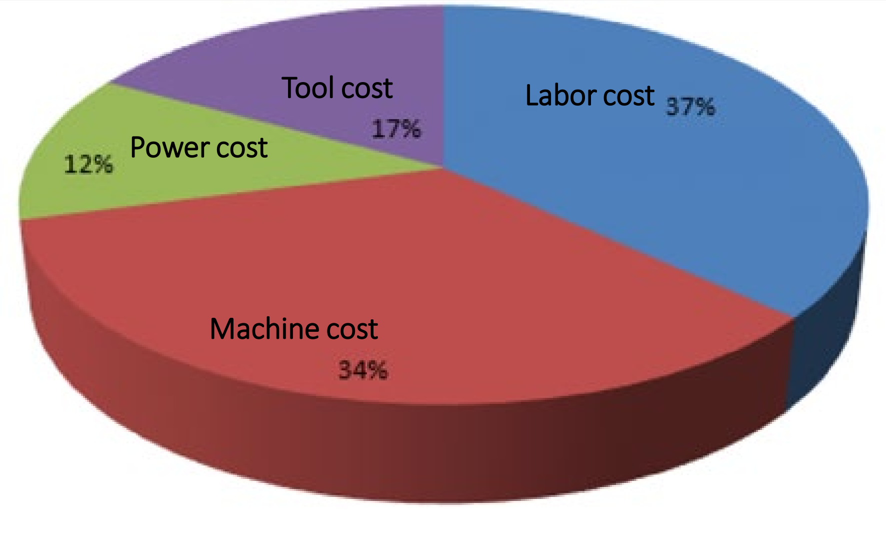


Relation between total cost and type of welded (FSW, MIG and TIG)

[16] A Comparison between FSW, MIG and TIG based on Total Cost Estimation for Aluminum Pipes



The cost distribution for weld joint fabricated using MIG and TIG process



The cost distribution for weld joint fabrication using FSW process

MIG and TIG vs FSW – Process costs [16]

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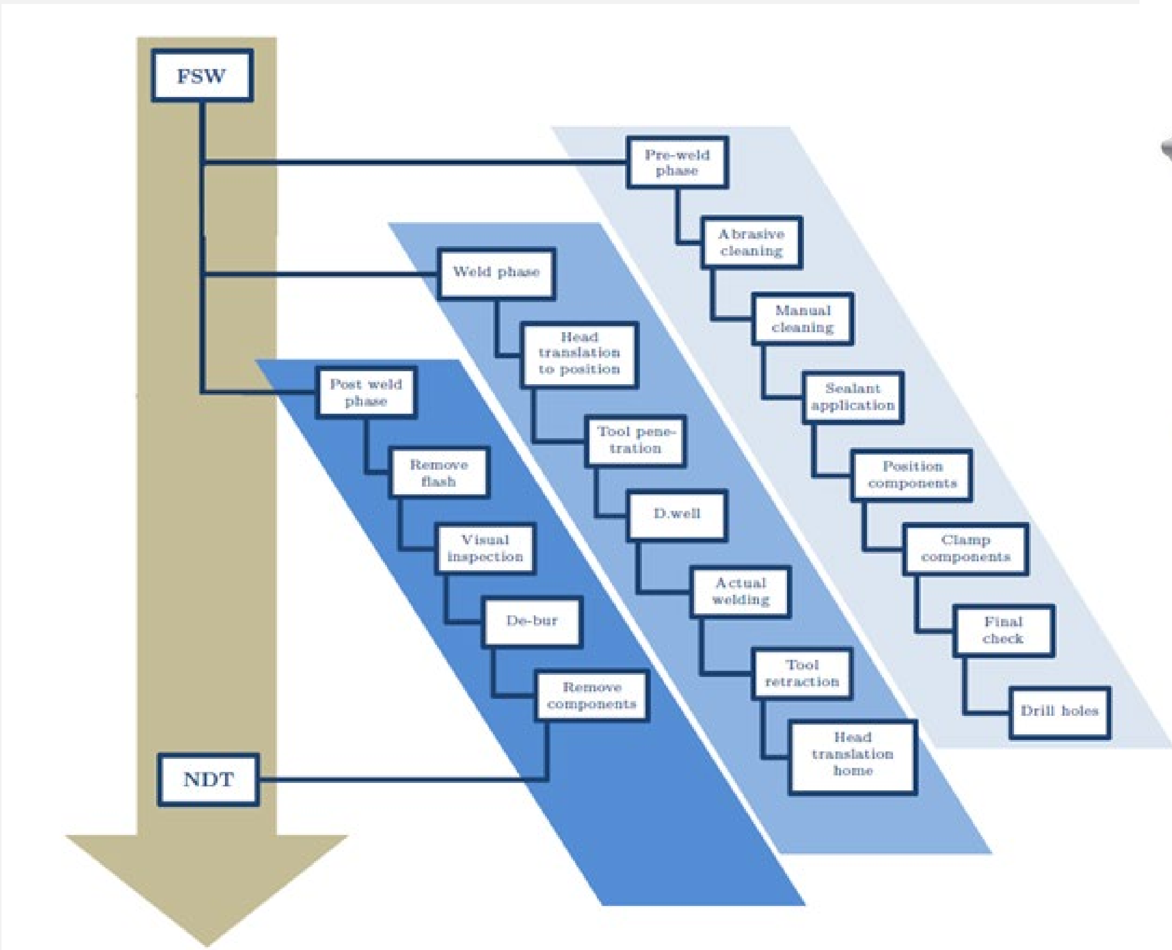
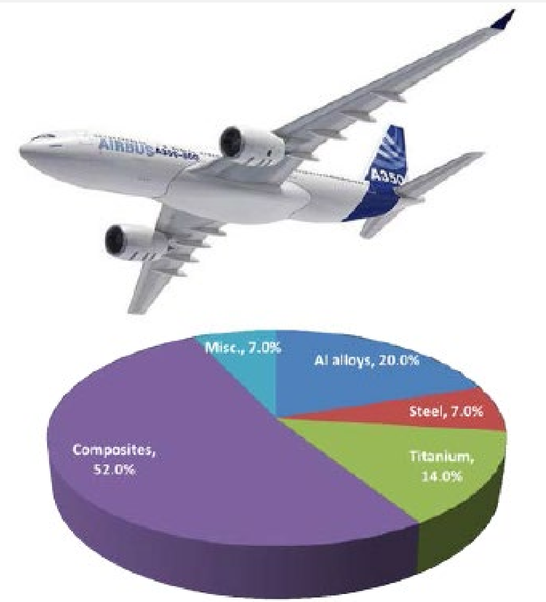
11.6 Requirements for FSW system installation



Phases and sub-processes of the friction FSW process [14]



(c) Airbus A350 XWB, 2013

[14] Design and Advanced Manufacturing of Aircraft Structures using Friction Stir Welding

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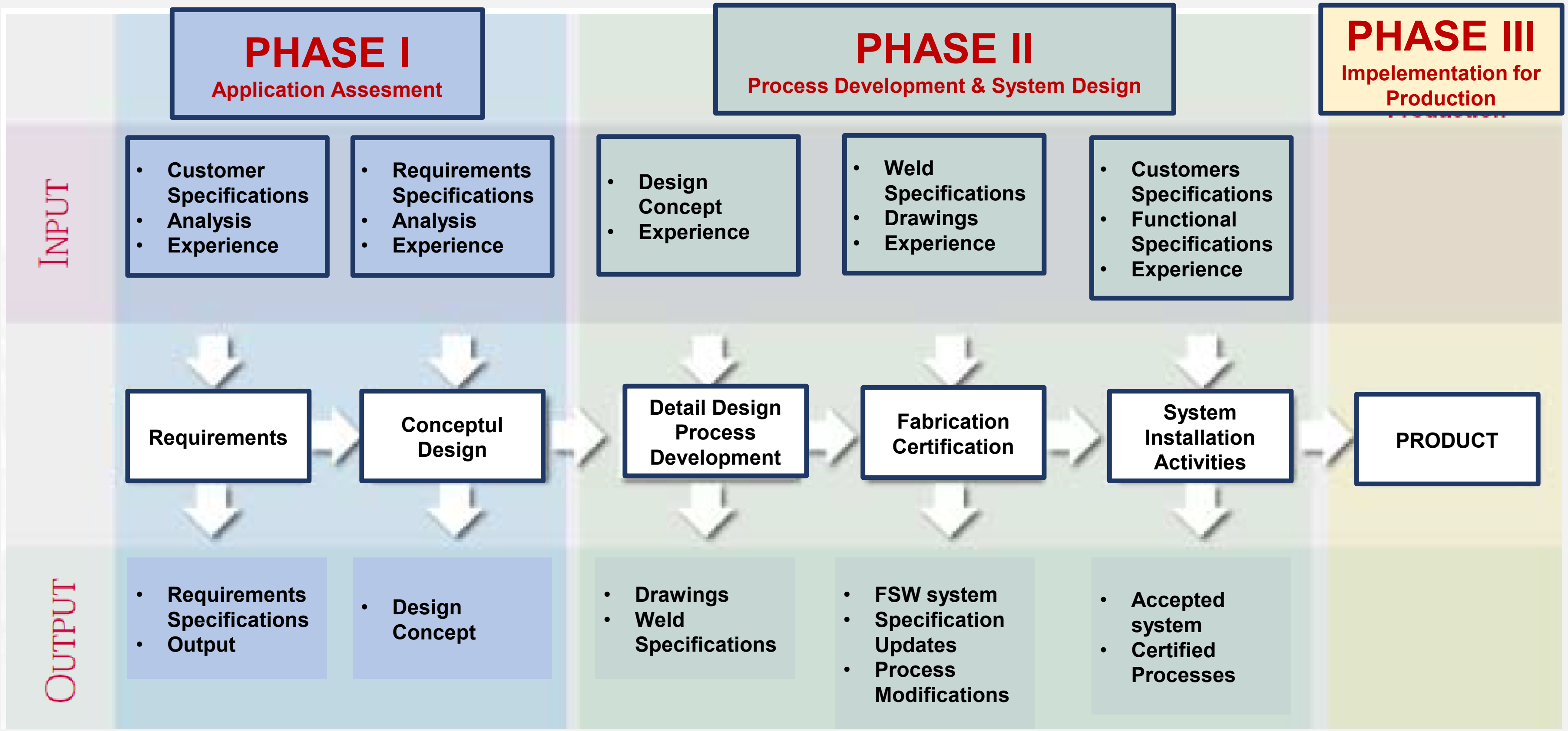

FSW Production Implementation [18]

[18] A progressive three-phase program to help you put FSW into production as efficiently and cost-effectively as possible.

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11.6 Requirements for FSW system installation

The ISOLATED FOUNDATION is required to **reduce** both active and passive vibrations. Vibration isolation mountings are required to reduce the transmission of vibration and shocks.

A **foundation block** or **vibration isolation mountings** for high dynamic machines like FSW machines, power press, forging hammers, compressors, engine test rigs etc. is required **in order to reduce the transmission of vibration and shock to nearby precision equipment** or building structures. To control the source of vibration disturbance through the use of resilient insulating materials is known as ACTIVE VIBRATION ISOLATION.

When it is not possible to prevent or sufficiently lower the transmission of shock and vibration from the source, a resiliently supported vibration insulating foundation block can be used for the PASSIVE VIBRATION ISOLATION of sensitive equipments like CNC equipment, Measuring & Control Systems, and Laser Tracking Systems.

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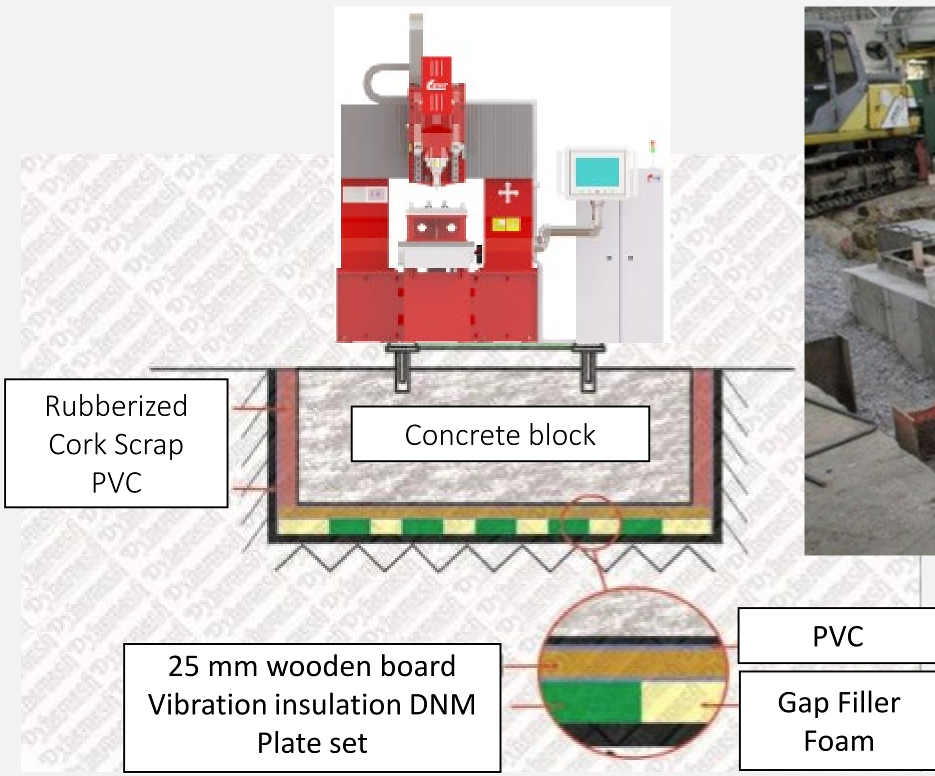
ISOLATED FOUNDATION lowers the center of gravity of the machine foundation system and **adds to the stability of the machine**. Machine remains aligned during dynamic load changes and rapid movements within the machines



Precise levelling ensures the correct angle geometry of the machine's axes and is necessary also for coolant and oil drainage.

Example of foundation block or **vibration isolation mountings** for high dynamic machines

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11.8 Quality control

Examination

Accordingly to DIN EN ISO 25239-5, the surface defects can be detected by **visual inspection** (macroscopic examination), with the exception of **insufficient penetration welding**. Others tests for weld quality assessment are:

- ✓ Tensile test
- ✓ Bending test
- ✓ Hardness measurement
- ✓ Metallographic examination
- ✓ NDT control

DIN EN ISO 25239-4, a 100 % visual inspection of finished friction stir welds is mandatory in order to meet the requirements for the qualification of a welding process for friction stir welding of aluminium.

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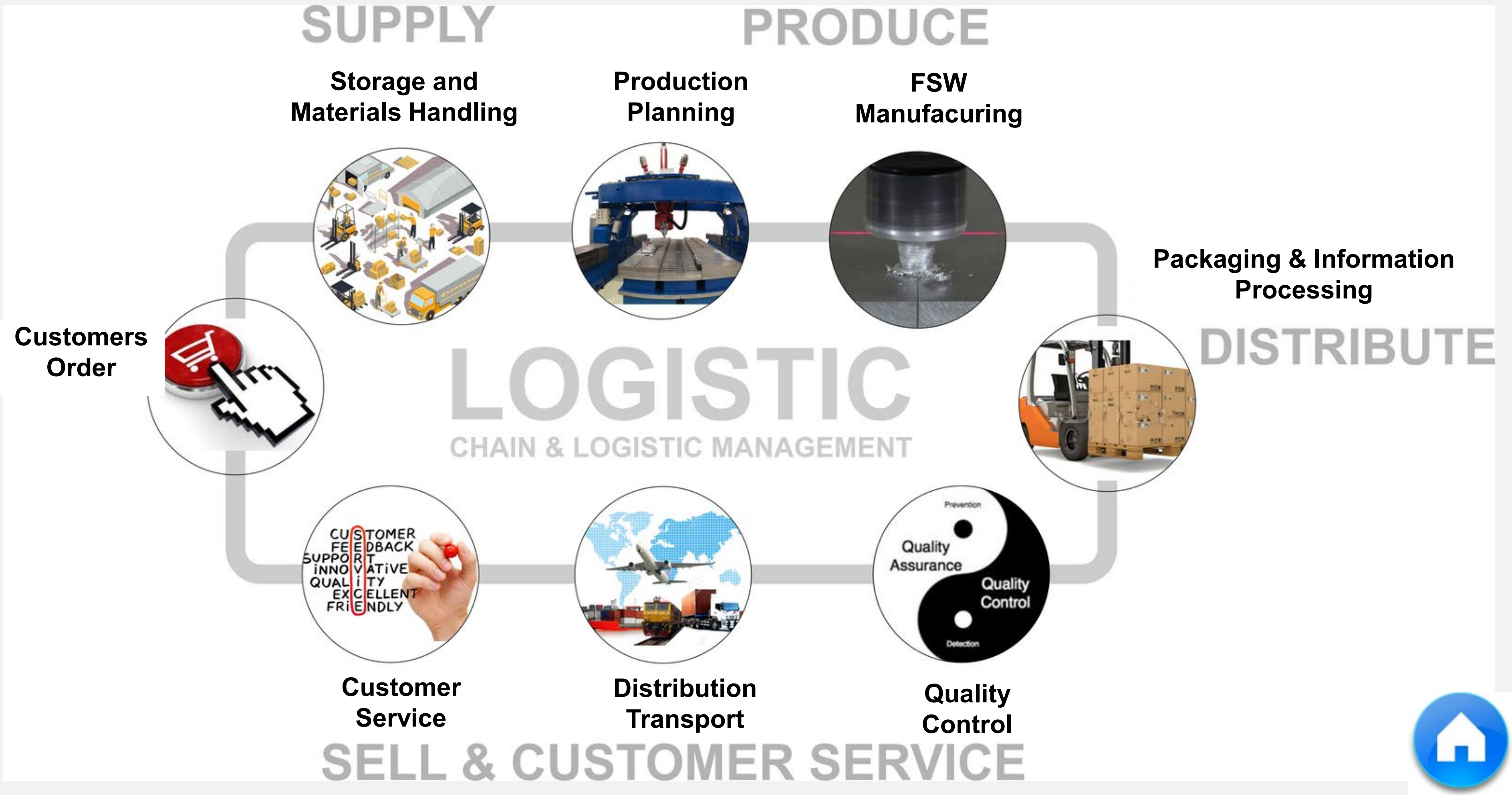
11.9 Logistics



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11.9 Logistics

The 6 Rights of Logistics

The RIGHT goods

in the RIGHT quantities

in the RIGHT condition

delivered…

to the RIGHT place

at the RIGHT time

for the RIGHT cost

These customer expectations define the purpose of a logistics system—it ensures that the right goods, in the right quantities, in the right condition, are delivered to the right place, at the right time, for the right cost. In logistics, these rights are called the six rights.

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11.10 Engineering network (electricity, air pressure)

Typical process utilities include **electricity**, process steam, refrigerants, **compressed air**, **cooling water**, heated water, hot oil, process water, demineralized water, municipal water.

The utilities costs are useful to process engineers, project planners, and utilities engineers in all manufacturing industries where plant utilities are essential parts of all production operations.

Utility piping systems are specified on a separate PFD for each utility, often known as utility flow diagrams. These diagrams indicate where utility pipelines connect to process lines or equipment and show the interconnecting headers.
Piped utilities consist mainly of steam, **compressed air**, **process and cooling water systems** but also include **inert gas**, vacuum and firefighting water.

The most common PFD symbols in use today come from agencies such the International Organization for Standardization (ISO 10628 – Flow Diagrams for Process Plants), the German Institute for Standardization (DIN) and the American National Standards Institute (ANSI.)

A **typical PFD** for a single unit process will include these elements:

- **Major equipment:** Including names and ID numbers. Examples include FSW machines, compressors, pumps, CNC equipment, and coolers units.
- **Process piping:** Moves the product, usually fluids, between equipment pieces.
- **Process flow direction**
- **Control valves and process-critical valves**
- **Major bypass and recirculation systems**
- **Operational data:** Such as pressure, temperature, density, mass flow rate and mass-energy balance. Values often will include minimum, normal and maximum.
- **Composition of fluids**
- **Process stream names**
- **Connections with other systems**

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11.13 Post processing operations FSW

- Post processing operations FSW is for example **Key-hole filling**. In HZG – Hamburg it has been developed a technology for crater filling. The crater is formed at the end of the weld and may require a **post processing operation** (or Friction Riveting).
- Grinding operations if is necessary, if the crater is too big and it can be filled. In general, it is preferable to avoid too many operations after the FSW process.

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