Manufacturing

Reliable Connections Achieved by Monitoring Joining Forces

13th Paderborn Symposium on Joining Technology
Mechanical Joining
Adhesive Bonding
29-30 November 2006

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Preface

These days industry in general and automobile manufacturers in particular are demanding more and more systems for monitoring joining processes such as resistance welding, clinching, self-piercing riveting and other assembly operations. This paper draws on application examples from LWF Paderborn and other sources to present special systems for calibration and analysis of joining forces as the basis of reliable process monitoring.

Despite joining and press-in techniques being in very common use, non-destructive mechanical testing of the results is virtually impossible. However, analysis of the force-displacement characteristics typical of each method has proven effective time and again. In addition to using direct measurement, the joining forces can be detected indirectly using the proportional strain induced on the surfaces of machine tool elements such as clinching guns, on which piezoelectric strain sensors are very readily mounted. Integrated electronics, compactness and robust industrial system design make these sensors very suitable for use in the production environment. This paper also shows how mounted strain sensors can be calibrated with very flat, internally preloaded force links.

Another way of boosting reliability is to simulate joining processes at the design stage, which will also be exemplified.

Resistance Welding

The critical welding parameters are time, current and welding force. Perfect spot welding can only be achieved if the welding (electrode clamping) force has reached a required value before the welding current is turned on. The welding force is defined as the force with which the two electrodes press the parts to be joined together for example, sheet metal. Switching the current on too early, before the force has reached, for example, 90 % of its desired value, causes increased electrode wear and spatter. On the other hand to keep the cycle time as short as possible the current should be applied at the earliest possible moment.

Direct and indirect force measurements are a suitable means of monitoring and possibly also controlling and regulating the force applied during spot welding (Fig. 1):
A) Periodic direct manual measurement (offline) of the welding or clamping force with a force sensor or by introducing a test station with built-in force sensor
B) Indirect measurement of the welding force during welding (online), for example using strain sensors in the pedestal or electrode holder
C) Direct measurement of the welding force during welding (online), for example using special force sensors integrated into the structure or directly in the drive motor

Fig. 1: Examples of force measuring systems on welding robot
To achieve a reliable welding process all parameters must be programmed into the control system before welding starts. Reference force sensors can be mounted between the electrodes to allow calibration of the correct welding forces.

Practical experience shows that the welding force can easily change from weld to weld. Large differences can arise if, for example, sheet metal is fed incorrectly or bent, so that the parts being joined do not lie flat on each other.

Figures 2 and 3 allow comparison of direct force measurement using an annular force sensor integrated into the electrode with indirect force measurement using a strain sensor mounted on the electrode arm.

Further evaluation of the force curves also allows conclusions to be drawn about the settlement of the weld spot during the welding process. In the case of spatter a significant force pulse can be detected. This is because, as a result of material being thrown out of the joining zone, the thickness of the weld spot is reduced, and this is manifested in a significant drop in force during or at the end of the weld interval.

The accuracy of the welding force as a function of time is a crucial quality attribute with both pneumatically and electrically actuated welding guns. In modern robot control systems the welding gun is used with electric servomotors as the 7th axis, so that online measurement of welding force can be used not only for monitoring but also for controlling the welding process [3-7].

**Clinching, Self-Piercing Riveting and Conventional Riveting**

Mechanical joining methods such as clinching, self-piercing riveting and blind riveting are becoming increasingly well established in the sheet metalworking industry and are used in a good proportion of modern products. Force monitoring prevents defective components from getting into volume production and ensures consistently high product quality. It also cuts production costs by eliminating the need for subsequent manual rejection of defective parts.

In some sectors, such as car making, clinched connections have already displaced spot welding as the most popular joining process. This trend has spread from secondary automotive components to relevant assemblies such as doors, hoods, trunks and tailgates.

Clinching is a method of joining pieces of sheet metal and profiles of different thicknesses and materials by pressing them together into a die that forms a connection similar to a rivet. This method uses local cold forming to produce permanent connections without additional or supplementary fastening devices. Its main feature is that it forms a positive connection from the material of the sheet metal to be connected.

One quality-determining parameter for monitoring the clinching process is the force necessary for plastic deformation. Kistler offers different measurement solutions for monitoring the clinching force curve.

In a similar way to the above-mentioned resistance welding applications, with clinching it is also possible to check the clinching gun periodically with a calibration transmitter, document parameters and adjust as necessary in the course of servicing and maintenance. This approach also allows calibration of sensors for indirect or direct force measurement in the machine (Fig. 4).
Continuous monitoring of the clinching curve with piezoelectric instrumentation from Kistler offers the option of indirect continuous checking of the long-term stability of a clinching unit consisting of drive and tool. This ensures the consistently high product quality synonymous with zero defect products. The elimination of any need for subsequent manual rejection of defective crimped connections also allows production costs to be reduced. Moreover, the process can be followed and documented.

Figure 5 shows a typical curve of clinching force against punch displacement for process analysis or monitoring.

Figures 6 and 7 show monitoring of the clinching force for the purpose of detecting a wide variety of defects, which may include:

- Dimensional discrepancies or wrong number of sheet metal workpieces
- Level of clinching tool wear
- Detection of process defects such as punch or die fracture
- Incorrect clinching height setting on press

Fig. 6: Monitoring of the base thickness from a curve of clinching force (Böllhoff)

Fig. 5: Joining force as a function of punch displacement for process analysis or monitoring (Laboratorium für Werkstoff- und Fügetechnik (LWF) of the University of Paderborn)

Fig. 7: Continuous monitoring of the curve of clinching force with piezoelectric strain transmitters. Typical defects detectable from curve of force against displacement (BTM)

Fig. 8: Metal broken out from die anvil [BTM]

Fig. 9: Die blade(s) not present [BTM]
Blind riveting is used primarily in positions only allowing access from one side. There are three different types of blind rivets:

**Expanding Rivet**
- The slit end of the tubular rivet is expanded by driving a notched pin into it.

**Pop Rivet**
- The pop rivet consists of a tubular rivet and a mandrel with tapered head. The rivet assembly is inserted into a hole drilled through the parts to be joined, then a hand or pneumatic tool is used to draw the mandrel into the rivet. This expands the end of the rivet and the mandrel is designed to eventually snap in a predetermined position.

**Blind Rivet Gun**
- In this case rivets with a female thread are inserted into the hole. The rivet tool is then introduced and drawn upwards to upset the metal under the workpiece. In this case as well the rivet force is also a critical process parameter that determines the quality of the process. Figure 11 shows a ControlMonitor for riveting process visualization and production monitoring for a pneumatic rivet gun with integral force measurement.

Integration of piezoelectric force sensors into a rivet gun and the process control system (CoMo View) makes it possible to respond to more stringent production requirements. The process of assembly involving permanent connection of components used in the production process can be monitored and documented. This prevents further processing of defective components and their eventual incorporation in volume production. CoMo View has a web server with integral 145 mm touch screen and can therefore be used for handling and monitoring the different riveting processes.

The big advantage is that production processes can be monitored from anywhere. The ControlMonitor is supplied in a sturdy desktop case.

The advantages of integrated process monitoring are obvious:
- Continuous checking of joining operation
- Good and bad parts distinguished immediately
- Complete riveting process can be documented
- Easy integration into existing LAN
- Remote monitoring and diagnostics if service needed
- Multilingual, intuitive operator guidance
- Quick exportation of process data in different formats
- Software for data export included in accessories

Typical application sectors include the manufacture of automobile parts whose documentation is mandatory and applications in which the rivet connection cannot be visually inspected.
Simulation of Joining Process

Another way of boosting process reliability is to simulate joining processes at the design stage. DEFORM is a finite element analysis program for simulating joining processes such as clinching or self-piercing riveting. Forming, heat treatment and machining processes can also be simulated.

Features of Simulation Tool DEFORM™:
• 2D and 3D FEM simulations on standard PCs or notebooks
• User-friendly, intuitive user interface
• Materials database with approximately 200 records
• Wizard for fast simulation of forming and joining processes
• Problem-free CAD importation using STL (3D), or IGS or DXF (2D), interface

FEM simulation allows quick comparison of different sheet metal thicknesses, materials, etc., as shown in the following diagram.

![Fig. 10: FEM simulation of different thicknesses of sheet metal being connected by clinching](image1)

Summary

The various sensor systems that have been presented are sufficiently sensitive and accurate to provide good and reliable force signals that can be used to analyze and monitor the process involved in many of today’s joining methods, such as spot welding, clinching, self-piercing riveting and conventional riveting. The sensors respond sufficiently quick to always allow perfect acquisition of the complete process curve, even when cycle times are extremely short.

Robust, largely overload-resistant and absolutely stable characteristics are not only essential for continuous, reliable monitoring of industrial production, but also form the basis for comprehensive documentation and online monitoring of the joining processes with the process control systems presented.

Kistler also offers a program package for the increasingly important simulation of manufacturing processes from the start of production.

References

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