Manufacturing

Force Measurement in Resistance Welding

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1. Introduction
With the pressure of competition increasing all the time, car body manufacturers in particular are being compelled to seek faster cycle times and more reliable parameterization for their resistance welding operations. To obtain the higher levels of process reliability that are desired, special attention has to be paid to the precision of the welding force over time, a critical quality characteristic for both pneumatically and electrically driven welding clamps. As welding clamps driven by electric servo-motors serve as a seventh axis in modern robot control systems, online welding force measurements can be used not only for monitoring but also for controlling the welding process [1-3].

Failure to ensure the timely detection of faults in spot welding clamps or incorrect process parameters in resistance welding can result in production waste or defective parts. To remedy such faults, it is generally necessary to carry out additional unscheduled overhauls [4].

Regular checks or on-line measurements of clamping and welding forces serve to permit such faults in welding robots or in the welding process to be detected in good time. Thanks to new developments in this field, dynamic and even online measurement of these forces during resistance welding is becoming increasingly popular, especially with electrical drive systems in welding clamps.

2. Process Parameters in Resistance Welding
The critical parameters in the welding process are time, current and welding force. For optimum spot welding, the welding force must have reached a desired value when the current is switched on. Welding force is understood to mean the electrode clamping force, the force exerted by the two electrodes as they clamp together the parts to be joined (e.g. sheet metal). If the current is switched on too early – i.e. before the force has reached for example 90 % of its maximum value – welding spatter and electrode wear can result. On the other hand, the current must be switched on as early as possible in order to keep cycle times to a minimum.

Direct and indirect force measurements are very suitable for monitoring and also, where applicable, controlling and regulating the force in spot welding:
A) Periodic direct measurement (off-line) of the welding or clamping force by manual measurement with a force sensor or by coupling to a test station with an integral force sensor
B) Indirect measurement of the force during welding (online), e.g. by means of strain sensors in the machine frame or the electrode holder;
C) Direct measurement of the force during welding (online), e.g. by means of special force sensors integrated in the structure or directly in the drive motor.

![Fig. 1: Examples of force measurement systems in welding robots](image-url)
To ensure the integrity of the welding process, all of the parameters must be fed or programmed into the control system from the outset. To this end, force sensors can be fitted between the electrodes as references in order to obtain the correct adjustment of the welding forces.

We know from experience that the force can vary from one spot weld to the next. The main reason for this is electrode wear, which gradually reduces the clamping force. Large deviations may arise for a number of reasons (e.g. if the sheet metal is not fed in correctly, or is the wrong thickness, or is deformed, so that the parts do not lie flush with each other.

3. Offline Monitoring
3.1 Periodic Calibration
The welding forces on welding robots and machines can be periodically checked, documented and, where applicable, adjusted within the framework of service and maintenance by means of the Type 9831C welding force calibration transmitter. It can also be used for the calibration of sensors for direct or indirect force measurement in the machine.

In combination with the Type 5825A2 welding force monitor, the Type 9831C welding force calibration transmitter records the force curve when the electrodes close and simultaneously registers the point at which the current is switched on. In this way, it is possible to check directly whether the clamping force has reached the desired level (usually 90 % of the maximum force) when the current is switched on.

The important thing here is for the force to be measured when electrode gap is as small as possible, respectively the same as for welding. In this respect, the Type 9831C transmitter offers a big advantage, as the welding force can be measured with an electrode gap of 3,0 mm, i.e as it would be in practical operation with 3 mm electrodes, Type F. Moreover, the electrodes need be separated only to a maximum of 11 mm to fit the calibration transmitter between them.

The transmitter consists of two steel plates with the actual sensor element mounted between them. A range of electrode adapters ensures that the force can be optimally transmitted to the sensor with electrodes of many different kinds.

3.2 Periodical Monitoring
Another possibility is the periodical monitoring of the welding force in the course of production. To this end, the Type 9833C... the welding robot is periodically connected to a welding force test transmitter at a fixed test station (e.g. the welding cap machining station).

When a car body shell is being built, the electrodes are typically remilled after 400 to 500 spot welds. This is a necessary programmed interruption of production, which is used for simultaneous checking of the welding clamps. At the milling station (Figure 3), the welding current and the welding force are checked and the electrodes are visually inspected.

Fig. 2: The Type 9831C... welding force calibration transmitter with welding monitor Type 5825A2 records the force curve when the electrodes close and indicates the main parameters (e.g. point at which current is switched on)

Fig. 3: The Type 9833C... welding force test transmitter integrated into a machining station (cap miller, optical sensor, current sensor and welding force test transmitter) used at BMW
The following process parameters can be checked from the measured welding force values, in conjunction with the programmed process parameters from the SPS:

- Comparison of maximum welding force with target force within given tolerances (e.g. 10%)
- Start of welding current at >90% of the target welding force
- Timing of maximum welding force (rising force, constant force during the welding cycle)
- Chatter behaviour of the welding clamps
- Comparison of the force and time curves with the programmed values of the control system
- Whether or not the air pressure is OK

Figure 4 presents two welding force curves recorded at BMW. The curve above shows an optimum welding force progression, where the programmed start time for the current is correct. In the curve below, the impact bounce when the electrodes come together is clearly indicated. In addition the programmed start time for the current at 90% of target is 35 ms and needs to be delayed by the same amount.

The advantage of the periodical monitoring described here lies in the early measurement of the welding force at the active point of the welding process, i.e. without delay and without damping by the mechanical structure. Where faults are detected, the welds have to be checked in accordance with the type of error, which may mean checking back to the last correct measurement.

### 4 Online Monitoring

Online monitoring permits direct conclusions to be drawn about the welding process. For example, the force profile of a servo clamp can be precisely described and it may even be possible to carry out a controlling of the process (e.g. adjustment of the welding force and the electrode displacement).

It is generally impossible to mount the sensors directly in the electrode or the electrode holder and, in any event, this would interfere with the welding process. Accordingly, for the purposes of online monitoring, the sensors are integrated in the load-bearing part of the machine structure. With welding clamps, they are integrated in the clamp holder or directly in the drive.

#### 4.1 Force Monitoring in Resistance Welding Machines

The indirect measurement of welding force – i.e. the resulting strain in the loaded structure – is particularly suitable for C-frame welding machines. The welding force generates relatively small but easily measurable strains in the machine structure or in the clamps. For the measurement of very small strains in structures, the highly sensitive Type 9232A... strain sensor and the Type 9234A... strain transmitter with integral electronics are both recommended.

The strain sensors are fixed to the loaded structure with an M6 screw. The mounting requires no more than a very small but finely machined flat area. The sensor is located at a point where the strain is well – and as far as possible – linearly-correlated with the welding force. Figure 5 (left) shows the Type 9232A... strain sensors on the C-frame (positions 2 and 3) and, for purposes of comparison, mounted on the electrode (position 1).
The Type 9831... welding force calibration transmitter referred to above can be used for calibrating the installed strain sensors to the welding force. The strain sensors supply an electrical charge signal proportional to the strain at the mounting point of the sensors. In Figure 5b, the raw signals (electrical charge [pC]) from the strain sensors are represented in comparison with the welding force sensor (sensors 1 and 2 only).

The strain sensors display very different sensitivities in relation to the welding force, depending on the location at which they are mounted. Sensor 1, mounted directly on the electrode holder, is markedly more sensitive than Sensor 2 on the frame. In addition, the strain signals are in opposite phasing, the mounting area of Sensor 1 being stretched while that of Sensor 2 is compressed.

Nevertheless, the welding force – and thus the welding process – can be quite well represented with the two strain sensors. Figure 6 illustrates a real welding process. The lower part of the diagram represents the control signals for the start of the cycle (pedal switch, current control signal). The welding parameters that have been set can be monitored from the force curves. This includes not only the welding force itself but also the squeeze, weld and hold times. Other features that can be detected from the force curve during welding include faults such as spatter and electrode wear.

Investigations into the use of force and strain recording devices for the monitoring of the welding process were conducted at SLV Duisburg on various resistance welding machines. The investigations included the analysis of force and strain recording devices on a projection welding machine, as shown in Figure 7.
Figure 8 shows some typical force measurement in projection welding. The violet curve shows the current, the black curve the path and the other curves those of the individual force sensors. Each individual force curve represents the welding process very well. The varying force amplitudes are probably attributable to a tilting of the electrodes or to an off-centre force input.

Figure 9 shows the indirect force signals recorded with a Type 9234A... strain transmitter on the upper support of a projection welding machine similar to the one shown above. A force measurement of this kind makes it possible to regulate the projection welding process. For example, when working with very soft materials like aluminium, this serves to ensure that the projection is not mechanically “flattened” before the actual welding process starts. Figure 9 shows such force curves, from which the first contact of the electrode with the projection is clearly to be seen. After the initial measurement, the process time can be shortened.
4.2 Force Measurement on Robot Welding Clamps

The strain sensors and transmitters that we have been describing for the indirect measurement of welding forces, as well as force sensors integrated in the drive structure or directly in the drive motor, are also suitable for use in force measurement on robot welding clamps.

A pneumatic C-clamp was used to carry out comparative measurements between the strain on the electrode and that on a force sensor integrated in the piston rod. The strain signals and the direct force measurements show equally good, reproducible results in relation to an online welding force monitoring (Figure 10, bottom left). As sensors on the electrode are not sufficiently protected for the production environment, a practical solution could well be to integrate the force sensor directly in the piston rod (Figure 10, bottom right).

Fig. 10: Integration of standard sensors in C-welding clamps: Type 9232A... strain sensor and Type 9031A force sensor
Figure 11 (left) shows a modern servo welding clamp, on which a Type 9234A... strain transmitter with integral electronics has been mounted in such a way that the welding process is unimpeded and the sensor receives optimum protection. The integrated electronic circuitry has an adjustable amplifier permitting the sensor to be optimally tuned to the welding forces and the process.

The advantage of using strain sensors or transmitters is the simplicity of mounting, particularly for the retrofitting of existing welding machines and welding clamps.

Figure 11 (right) shows a force transmitter for direct force measurement integrated in a spheric bearing, as typically used in servo-electric clamps.

This type of indirect force measurement is used for monitoring or, as shown in Figure 12, for constant force regulation in spot welding with servo-electric clamps. It also serves to optimize the timing of the actual welding processes (Figure 12 right), as well as to regulate correction of weld joints.
4.3 Force Sensors Integrated in the Drive Motor

The ideal solution for electrically driven welding clamps is certainly to integrate the force sensor directly in the drive motor. Modern welding clamps have electric servo motors in which the rotation of the primary drive is generally converted into linear motion by an integrated transfer drive.

Figure 13 offers a schematic representation of a linear motor with the integrated force sensor for measurement of the axial force $F_z$, which is proportional to the welding force. This type of integrated force measurement has already been developed and successfully tested on machine tool spindles for machining centres [5].

As to practical applications, a special force sensor with the related electronic circuitry for integration into a new generation for air and water-cooled electric drive motors has been developed for C and X-welding clamps and has been in successful operation since the beginning of this year (Figure 14). The force sensor is designed for a measuring range of up to 20 kN and is fully integrated in the KUKA software KRC2 V6.0 and the ARO Controller (servo-box 2002, i.box).

Fig. 13: Schematic diagram of an electric motor with integrated special force sensor for measurement of welding force

Fig. 14: Robot with electrically driven welding clamp and integrated force sensor
5 Summary

The sensor systems presented here, for both online and offline calibration and monitoring are sufficiently sensitive to supply good, reliable signals for all resistance welding processes. The sensors respond with sufficient speed to provide a full and accurate record of the welding force curve even with the shortest cycle times. Moreover, as the sensors are, by their nature, not affected by electrical and magnetic fields, the signals produced are reliable, as well as clear and easy to analyze.

Thanks to their absolute stability and very high capacity to withstand overloads, these rugged sensors represent not only a sound basis for reliable, long-term monitoring and even control of industrial welding processes but also for seamless production documentation.

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