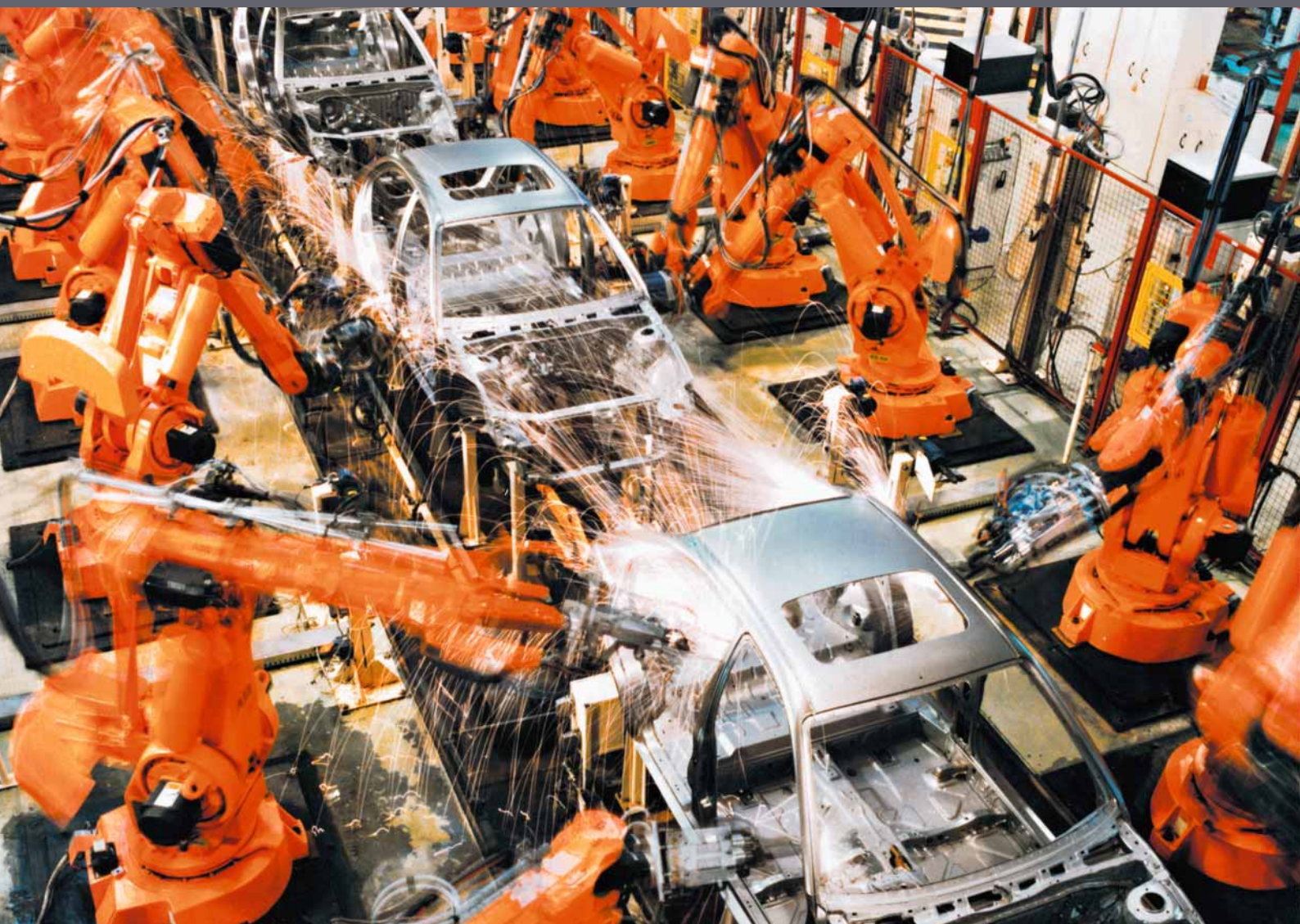


Hot-spot robotics

Improving productivity and quality in automotive spot welding

Bin Niu, Yonglin Chi, Hui Zhang



China recently surpassed Japan as the world's second largest automobile market after the United States. Annual output of automobiles is close to six million units a year. A key tool in automotive production is the spot welding gun and the industrial robot. One of the most important parameters of a spot welding gun is force tolerance. ABB is helping the Chinese automotive industry improve welding productivity and quality by developing new techniques for controlling force tolerance.

Resistance spot welding is widely used by the automotive and aerospace industries as one of the major joining processes for sheet metal work pieces. Although many innovative technologies for sheet metal joining have been proposed in recent years, spot welding maintains its predominant status in body-in-white (BiW) assembly due to its low cost and high efficiency in automated production.

In recent years it has become increasingly popular to use a spot welding gun driven by an electric servo motor rather than the traditional pneumatically driven welding gun. This is due to its better welding performance and quality, which is made possible by the accurate control of the servo motor's position and torque. Major automobile manufacturers such as Renault, Mazda, Toyota and Ford choose servo welding equipment for their car body assembly lines instead of conventional pneumatic equipment.

Welding guns driven by AC servo motors tend to be mounted on the manipulators of articulated industrial robots and configured as external axes. They are controlled in a coordinated way with the innate six axes of robots. Control instructions sent by the servo controller, which is part of the robot controller, drive the servo motor at a velocity and torque predefined by the robot programs. The position and velocity of the electrodes are controlled respectively by the

quantity and frequency of pulses sent to the motor, with the clamping force between the electrodes dependent on motor torque 1, 2.

Precision control of the welding clamps improves the productivity and quality of the welding process greatly. Welding cycle time is significantly reduced by the fast torque of the servo gun in the squeeze phase. On average, it takes a servo gun only 8 cycles (0.16s) to reach the predefined pressing force; whereas for the pneumatic gun, it takes 30 cycles (0.6s) – a saving of 0.44s for a single spot. Multiply this by the thousands of spots welded in a car and the savings become immense. Cycle time is further reduced by the coordinated movement of the servo gun with the manipulator, which enables the gun tips to close while the servo gun is moved from one spot to another by the robot. Welding quality is also much improved.

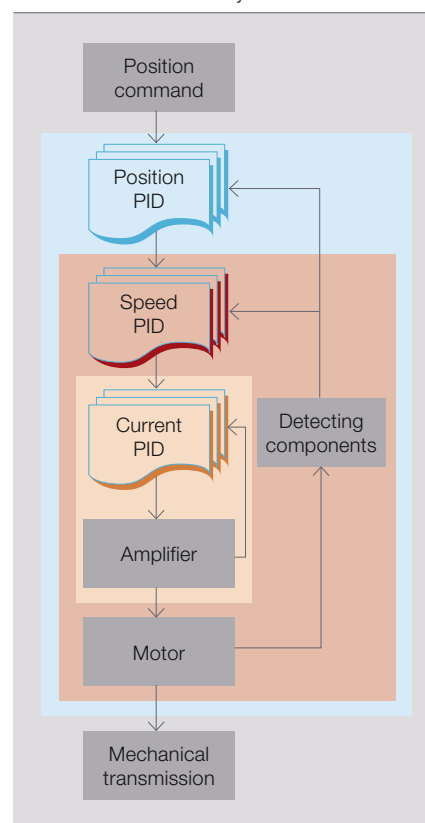
Despite its many strengths, the servo gun does have some limitations. It is well known that the most critical parameters for spot welding are time, current and welding force. Of these, the welding (electrode clamping) force with which the two electrodes press the sheet metal pieces together, is a key factor that determines welding quality. Although the force tolerance of the servo gun is much better than that of the pneumatic gun, the output force accuracy of the servo gun is still subject to some negative

influences. How to relieve or eliminate those influences to ensure that the predefined welding force is accurately executed on the work pieces is essential for welding reliability.

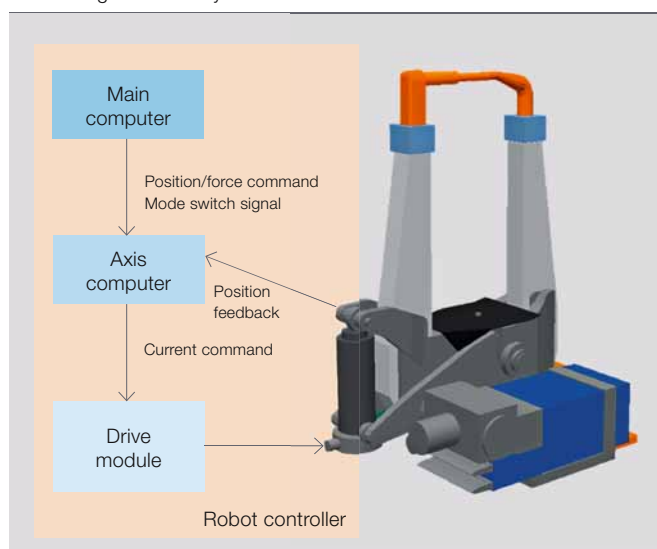
Negative influences on the servo gun

3 shows the output force of the servo gun in torque control mode and 4 shows the negative influences – tem-

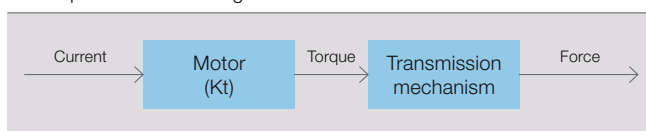
1 Servo motor control system



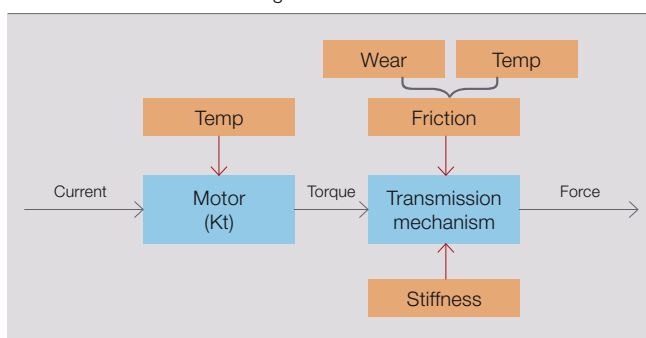
2 Servo gun control system



3 Output force of servo gun



4 Influence factors on servo gun



Robotics

perature, wear, and stiffness – on the servo gun's output force.

Temperature

Temperature influences the force flow in two respects and with opposite effects. Firstly, the temperature of the motor increases – due to the Joule heat generated by the welding current and the heat generated by the motor itself. Even if a constant current is supplied to the motor, the output torque of the motor will decrease and the output force will also decrease as a consequence. Second, friction loss in the transmission mechanism components, including the ball screw/nut mechanism and the arms, will be lowered by the rise in temperature, and reduced friction will result in increased output force.

Wear

Wear and tear in the transmission mechanism of the servo gun is another factor that causes friction loss. After a period of use, a servo gun develops a more efficient transmission mechanism than a new one. This causes less energy loss due to decreased friction. Although a well-calibrated servo gun performs accurately when it is first installed, it often needs to be recalibrated after a period of time. Variations in the amount of friction in the mechanism can account for this.

Stiffness

Stiffness in the mechanical arms of the welding gun can also cause deviations in output force. For instance, if the arm of the gun is too weak, it will bend when a relatively large force is applied to its tip. The greater the deformation, the worse the accuracy and linearity of the output force.

Various solutions that aim to enhance output force performance with improved accuracy are presented below. They are categorized according to whether the control loop is completely closed or completely open in relation to the target.

Open loop force regulation

Although the driving current of the motor is regulated in a closed loop manner in the traditional control method of clamping force **1**, the transfer process from current to force

is left open. In other words, no force information is fed back to the axis computer for closed loop force regulation in real time. Solutions that regulate the clamping force on the basis of an open force loop fall into this category.

Force feed-forward control

Feed-forward control is a strategy used to compensate for disturbances in a system before they affect the controlled variable. A feed-forward control system measures a disturbance variable, predicts its effect on the process and applies corrective action.

According to modern control theory, it is possible to estimate disturbance by a disturbance observer and remove it by the feed-forward control method so that the controlled target improves its immunity to disturbance.

Temperature compensation

Small motors attached to servo guns tend to be more susceptible to temperature influence than larger motors. This has been solved by either using water cooling motors or larger motors that accept a higher force tolerance. But water cooling requires a more complex motor design and may cause water pressure to drop in the welding system due to leakage. Consequently, the current trend is to move away from water-cooled motors towards greater accuracy in force. This requires a better understanding of the influences on motor temperature and solutions that avoid the problem.

To realize temperature compensation in a servo gun control system, a temperature sensor needs to be mounted at a suitable position to detect the temperature of the servo motor or of the movable components of the welding gun. The sensor will send temperature information to the axis computer, where an adaptive temperature compensation function is integrated with the current control loop of the servo gun.

Results show that the relationship between variation in temperature and force is approximated by a linear function. Thus, a transfer constant can be used to represent the amount of force change per unit of temperature

change. After the target force is compensated in accordance with the temperature, a uniform pressing force can be produced without temperature variation.

Periodic force checks and recalibration

Since clamping force is not regulated by closed loops, it is important that force precision is stable and that excessive deviation of force is detected as early as possible. Failure to ensure the timely detection of faults in welding clamps, or incorrect process parameters in resistance welding, can give rise to production waste or defective parts. Periodic checks or recalibration of direct force is absolutely necessary.

A good time to do this is when production is interrupted to re-mill the electrodes. In a BiW workshop the electrodes are typically re-milled after 400-500 spot welds, as wear gradually reduces the clamping force. By integrating a force sensor with the other tools and sensors at the service station, the force value can be sent to the axis computer. There, a program verifies how much the measured force deviates from the command value and determines if force recalibration is necessary. If so, an automatic calibration program is run to complete recalibration automatically.

Compared to the alternative and less efficient method of using a handheld sensor, servo gun malfunctions are detected earlier (which reduces waste) and force checks and recalibrations are performed automatically (which improves productivity).

A hybrid dual-loop control strategy based on force and velocity is the ideal solution for servo gun control.

Closed loop force regulation

According to classical control theory, the control loop has to be closed on the control object to achieve accurate control of an output variable. But in resistance spot welding, it is not feasible to mount a sensor to the tip of the electrode for real-time force measure-

ment without interfering with the normal welding process. Therefore, alternative approaches to obtaining force information for closed loop regulation are necessary and a new control strategy is required.

Force measurement methods

In view of the infeasibility of mounting force sensors on the tip of the electrode, alternative methods for obtaining online force measurements have to be considered.

Force sensors can be mounted on other parts of the gun providing they do not interfere with the normal welding process and providing the sensor's output signals have a linear relationship with the clamping force. Alternative sensor locations are shown in **5**.

A strain sensor can be fixed to a point on the robot arm (A) where there is a small, flat area offering good linearity and sensitivity between strain and force. The sensor measures the strain in the mechanical arms of the welding clamp generated by the clamping force. This is a low-cost, simple, but indirect method to obtain a force signal. Alternatively, a force signal can be directly obtained by integrating a piezoelectric force sensor with the spherical bearing between the drive motor and movable arm (B). A third option is to integrate a force sensor with the drive motor for better protec-

tion from the harsh production environment. It can be placed against the rotary-linear motion conversion mechanism inside the motor to measure the drive force (C).

However, feedback control without a force sensor is an attractive option. One such possibility, using disturbance observer control, estimates an external load from the current command and actual velocity of the motor and then feeds back the estimated torque to obtain a force feedback measurement.

Control strategy

With a force sensor in the solution, the control system should have its own force feedback closed loop in which the force error signal directly drives the amplifier and motor. But the servo welding gun, which is controlled by a robot controller as an external axis of a six-axis robot, is position-controlled in the same way as the robot axes. This means that force control loops can only be closed around position/velocity control loops. Moreover, in the welding process the control of welding clamps frequently switches between position control and force control. A hybrid dual-loop control strategy based on force and velocity is, therefore, the ideal solution for servo gun control. It offers better performance than single loop, and it is easier for a robot controller to close the force loop around a low-level position/velocity controller.

Despite the extra hardware and software, the servo gun with closed loop force regulation is set to become the preferred method in spot welding, not only because it improves force tolerance but also because a dynamic force profile can be easily realized for special welding cases.

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5 Placement of force sensors on servo gun

