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- «Suchasna Elektrometalurhiya» (Electrometallurgy Today), https://patonpublishinghouse.com/eng/journals/sem;
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ORIGINAL ARTICLES

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*Translated Article(s) from “Avtomatychne Zvaryuvannya” (Automatic Welding), No. 1, 2026.

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ADVANCED DROPLET TRANSFER CONTROL AND PROCESS OPTIMIZATION IN PULSED MIG WELDING

ABSTRACT

The transition towards high-efficiency manufacturing requires advanced control over the pulsed gas metal arc welding (GMAW-P) process. This paper investigates the technological capabilities and industrial application of the AOTAI AMIG500P-i, a highly efficient pulse welding machine. By analyzing its hardware architecture — incorporating a 60 kHz inverter and 32-bit dual-core ARM processors — this study explores the physics and practical benefits of proprietary welding waveforms, including Fast Pulse, Deep-Penetration Pulse, and Hybrid Wave processes. The integration of Intelligent IoT for real-time data exchange and the system's adaptability to extreme production environments are also evaluated.

KEYWORDS: pulsed welding, MIG/MAG, fast pulse, deep-penetration, hybrid wave, intelligent IoT, 32-bit ARM, heat balance, AOTAI AMIG500P-i

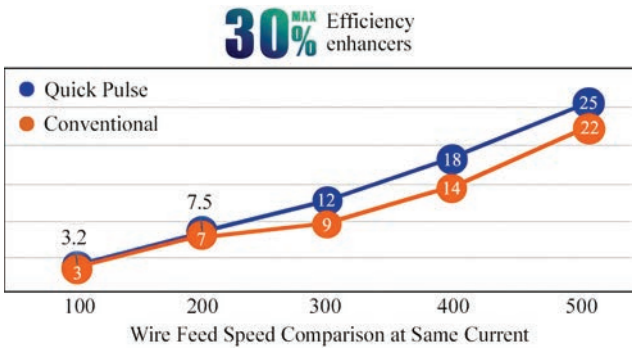
INTRODUCTION

In modern heavy industries, such as shipbuilding, offshore equipment, heavy machinery, and defense manufacturing, the demands for weld quality, penetration depth, and execution speed are increasingly stringent. Classical MIG/MAG welding methodologies frequently fall short in balancing high deposition rates with strict heat input control. To address these challenges, advanced pulse MIG welding machines have been developed, supporting both single and twin wire modes to maximize productivity.

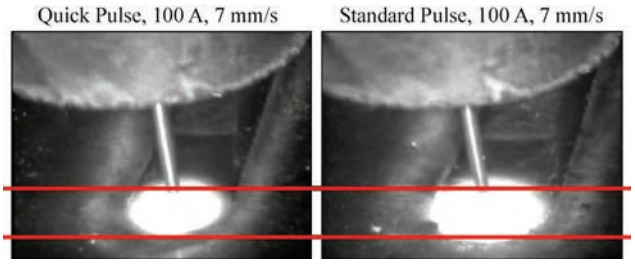
This article provides an in-depth technological review of the AOTAI AMIG500P-i, examining how next-generation high-frequency platforms facilitate precise arc control and improved overall welding performance across a diverse range of materials, including carbon steel, aluminum alloys, stainless steel, copper, and nickel alloys.

HARDWARE ARCHITECTURE AND INTELLIGENT CONTROL SYSTEMS

The foundation of the AMIG500P-i's performance lies in its sophisticated hardware design.



Quick Pulse. A quick pulse welding process developed for carbon steel, improving welding efficiency by 15–30 % compared to some machines from other manufacturers. It is especially suitable for industries such as semi-automatic construction machinery and specialized automatic welding equipment



Deep Penetration Pulse. Forms a pulse + spray transition with higher current density and greater arc pressure. Under the same current, the penetration depth improves by 30 % compared to traditional pulse processes, improving the fusion quality at the root of medium and thick plates

POWER SOURCE AND PROCESSING

The system is built upon AOTAI's next-generation high-frequency platform, featuring a 60 kHz inverter. This high frequency enables microsecond-level reactions to arc variations, providing precise droplet control and maintaining a strong, high-rigidity stable arc. The computational core consists of high-speed 32-bit dual-core ARM processors. This dual-core architecture is responsible for advancing multiple complex MIG processes simultaneously by executing precise waveform control in real time.

WIRE FEEDING AND EQUIPMENT

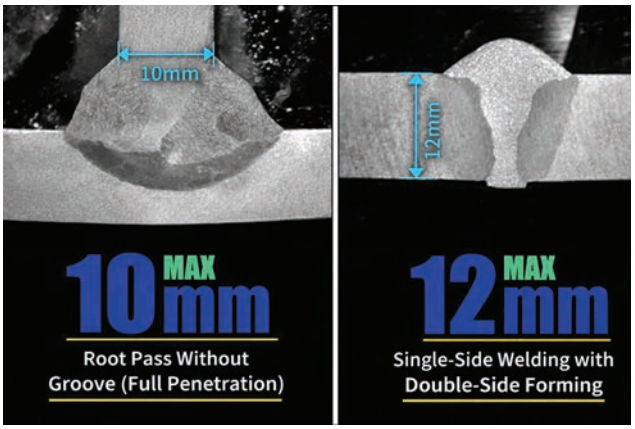
Compatibility Stable droplet transfer requires flawless mechanical support. The AMIG500P-i utilizes a dual-loop system paired with a torque motor to guarantee stable wire feeding. Furthermore, the system is highly adaptable to external equipment, seamlessly integrating with digital MIG/MAG torches, push-pull torches, and remote control boxes to suit various production setups.

DATA MANAGEMENT AND INTELLIGENT IOT (INTERNET OF THINGS)

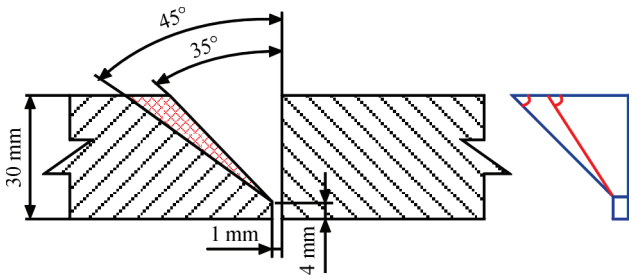
In the era of Industry 4.0, connectivity is paramount. The machine features an Intelligent IoT module that is 4G, 5G, and WiFi compatible, enabling real-time data exchange and smart factory integration. On the shop floor, operators benefit from one-key operation, allowing them to save and recall up to 100 sets of welding parameters, with an optional IC card (Integrated Circuit card) for secure user management.

HEAT BALANCE DYNAMICS IN PULSED WELDING

The physical advantage of the pulsed mode is the decoupled control of electrode melting and base metal heating. The effective thermal power of the arc q is governed by the integral equation of heat balance:



Advantage 1. Deep penetration process reduces groove size and saves material significantly



Advantage 2. Deep penetration process reduces the number of weld layers, saving time significantly

$$q = \eta \frac{1}{T} \int_0^T u(t) i(t) dt.$$

For rectangular pulse waveform engineering, this translates to:

$$q \approx \eta \frac{I_p U_p t_p + I_b U_b t_b}{t_p + t_b}.$$

By manipulating the peak phase (I_p, t_p) for droplet detachment and the base phase (I_b, t_b) for background heating, the AMIG500P-i prevents weld pool overheating. This strict thermal management forms the physical basis for its advanced proprietary processes.

ADVANCED WELDING PROCESSES AND INDUSTRIAL EFFICIENCY

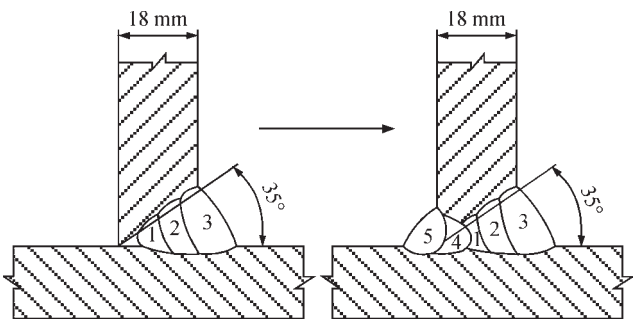
The processing power of the AMIG500P-i allows it to deploy several specialized waveforms that dramatically alter standard welding physics.

FAST PULSE PROCESS

Designed to maximize throughput in equipment manufacturing and steel fabrication, the Fast Pulse process boosts welding efficiency for carbon steel by up to 33 % over standard pulse welding. By modifying the droplet detachment frequency, the machine enables significantly higher wire feed speeds. According to empirical data, efficiency improvements scale with the current: a 6 % increase at 100 A (3.2 m/min), a massive 33 % improvement at 300 A (12 m/min), and a 13 % improvement at 500 A (25 m/min).

DEEP-PENETRATION PULSED WELDING ROOT FUSION

Defects in medium and thick plates are a critical concern in structural fabrication. The Deep-Penetration process modifies the arc force to deliver 30 % deeper weld penetration at the equivalent current. Comparative studies show that penetration depth increases from 5.38 mm (Standard Pulse)



Standard Pulse Process. Front-side root, fill, and cap, three layers and three passes; back-side root clean-up, two layers and two passes, total five layers and five passes. Deep Penetration Pulse Process: Front-side root (fully penetrated, single-side weld with double-side formation), fill, and cap, three layers and three passes; back-side no root clean-up, single layer and single pass, total four layers and four passes

to 7.37 mm (Deep-Penetration Pulse). From a practical standpoint, this technology radically changes joint preparation:

- It achieves 10 mm fillet welds with full penetration, requiring no beveling or back gouging.

- It supports 12 mm butt welds via single-side welding, allowing for free backside formation without beveling.

HYBRID WAVE PROCESS AND FISH-SCALE WELDING

The Hybrid Wave process introduces alternating dual processes to create highly versatile welding modes: pulse + short, pulse + pulse, and short + pulse. The “pulse + short-circuit” combination explicitly reduces heat input, effectively eliminating welding defects caused by excessive molten pool temperatures. This specific process is ideally suited for robotic vertical-up (3F) fish-scale welding, requiring no mechanical torch oscillation. It yields high-quality, aesthetically pleasing fish-scale welds on aluminum alloys over 1 mm thick, as well as on carbon and stainless steels.

OPERATIONAL ADAPTABILITY AND TECHNICAL SPECIFICATIONS

(industrial environments dictate that equipment must perform reliably under adverse conditions).

OUTPUT CAPACITY AND CIRCUIT COMPENSATION

Long cable runs typically distort high-frequency pulses due to circuit inductance. The AMIG500P-i overcomes this, maintaining stable welding and consistent arc ignition even with up to 45 meters of cable. Furthermore, it exhibits enhanced adaptability to various gas mixtures, delivering smooth bead formation and maintaining arc stability at 160 A when using standard 80 % Ar/20 % CO_2 mixtures, outperforming standard products.

TECHNICAL DATA

Built for demanding applications, the machine is available in a water-cooled model designed specifically for continuous high-current welding with superior cooling performance. The system operates on a 3-phase, 400V±10 % (50 Hz) input and delivers a 100 % rated duty cycle at an output of 500A/39V. Despite its immense power (24 kVA rated input capacity), the unit is relatively compact (66×32×56 cm) and weighs 55 kg, maintaining an IP23 ingress protection rating and Class H insulation.

CONCLUSIONS

The application of the AOTAI AMIG500P-i represents a significant advancement in GMAW-P technology.

- The integration of a 60 kHz inverter with 32-bit dual-core ARM processing provides the necessary computational speed for flawless, real-time droplet control and complex waveform generation.

- The Fast Pulse and Deep-Penetration processes substantially reduce manufacturing time and costs by boosting efficiency up to 33 % and eliminating the need for beveling on plates up to 12 mm thick.

- The Hybrid Wave process offers unprecedented thermal control, enabling automated vertical-up fish-scale welding across various alloys without mechanical oscillation.

- With a 100 % duty cycle at 500 A, IoT connectivity, and robust performance across 45 m cable lengths, the system proves to be an indispensable asset for heavy, intelligent manufacturing environments.

With materials from Welding Technology Center