Research on the process of cutting plastic sprues using a CO_2 laser driven by a Fanuc robotic arm

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Abstract: This paper presents an intelligent cutting system based on a Fanuc M-20iA six-degree-of-freedom industrial robot integrated with a CO_2 laser. The system achieves flexible transmission and stable control of the laser beam through a hollow arm structure and a built-in light-guiding arm. Combined with trajectory planning algorithms and process parameter optimization, it effectively enhances the precision and efficiency of gate cutting. This study provides a highly flexible and efficient automated solution for post-processing of plastic products, especially suitable for modern production needs with multiple varieties and small batches. The average processing time for a single piece of mechanical arm laser cutting is 7.8 seconds, significantly lower than the 22 seconds of traditional manual cutting, representing an efficiency improvement of approximately 64.5%.

Key words: Fanuc robotic arm; CO_2 laser cutting; plastic sprue; trajectory planning; process parameter optimization

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In plastic injection molding, the quality of gate removal directly impacts the product's appearance and competitiveness. Traditional removal methods often result in poor precision and damage to the product surface. Laser cutting, as a non-contact technology, offers advantages such as no wear, high precision, and good flexibility. Specifically, CO_2 lasers have an output wavelength that matches the absorption characteristics of non-metallic materials, enabling efficient melting and vaporization of plastics, making them particularly suitable for gate cutting.

However, traditional fixed laser equipment struggles to cope with the spatial morphology of complex three-dimensional gates. With the advancement of industrial robot technology, robotic laser processing systems, leveraging their flexible workspace, excellent motion performance, and high automation, offer an effective solution for laser cutting of complex three-dimensional components. Leading enterprises in the industry, such as FANUC, have successfully applied their robotic CO_2 laser cutting systems in fields like automotive interior and exterior trims, aerospace composite materials, demonstrating significant advantages in precision processing of non-metallic materials.

1 Composition and operating principle of robotic arm cutting system

The plastic gate cutting system, driven by a FANUC robotic arm and equipped with a CO_2 laser, consists of four major components: the robotic arm body, the laser generation system, the control system, and auxiliary devices. These components work together to form a highly flexible and precise automated processing platform, as shown in Figure 1.

1.1 FANUC Robotic Arm System

The core of the system utilizes a FANUC M-20iA six-degree-of-freedom industrial robot. This robotic arm boasts a

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Figure 1 Physical image of FANUC robotic arm cutting system

load capacity of 20 kg and a working radius of 1.8 m, making it ideal for gate cutting operations of small and medium-sized plastic products. The robotic arm features a hollow design, which integrates the laser light path internally, effectively reducing external interference and enhancing motion flexibility. This design meets the stringent requirements for path accuracy in laser cutting.

The robotic arm integrates visual zero-point correction technology and precision software, significantly enhancing the accuracy during small trajectory cutting. To address the potential collision risks in gate cutting, the system is equipped with a magnetic anti-collision cutting head that can quickly disengage and recover in case of a collision, minimizing equipment downtime.

1.2 CO_2 laser system

As shown in Table 1, the laser source utilizes an Iradion 250W CO_2 laser, emitting laser light with a wavelength of 10.6 μm, which can be efficiently absorbed by plastic materials, enabling rapid melting and gasification. The laser power can be continuously adjusted according to cutting requirements, adapting to the cutting characteristics of different types of plastics. The laser and the robotic arm are installed in an integrated manner, resulting in a compact structure and a simple and stable optical path. The beam quality factor M^2 of the Iradion laser is $\leqslant 1.2$, approaching an ideal Gaussian distribution, allowing it to focus on a very small spot, enabling precise cutting. Using fundamental mode output can reduce the kerf width by 25% compared to multimode cutting, and decrease the width of the heat-affected zone by 40%.

Table 1 Operating parameters of CO_2 laser system

Power level / W	200 and 250
Wavelength option / μm	10.6,10.2
Pulse option	standard
Cooling options	water cooling
Beam expansion/collimation	6 times, 5 times, 4 times, 2.5 times

1.3 Control system

The control system is detailed in Figure 2.

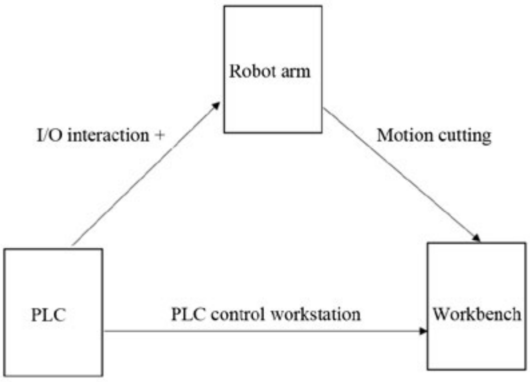

Figure 2 Main control methods of equipment

1.4 Auxiliary system

The light guide system consists of a built-in light guide arm and a red light positioning module. The light guide arm transmits laser light from the generator to the cutting head, with high-quality reflective lenses inside to ensure laser transmission efficiency and beam quality. The red light module can display the predetermined path before formal cutting, facilitating operator verification of trajectory correctness and reducing scrap rates caused by programming errors.

The cutting head integrates a focusing lens and an auxiliary gas nozzle, with the focal length adjustable according to the geometric characteristics of the sprue. The auxiliary gas system provides clean compressed air or inert gas, which is used to blow away molten material, suppress combustion, and cool the edges of the cut slit, thereby improving the cutting quality.

2 Trajectory planning for robotic arm cutting system

The geometric characteristics of plastic sprues are closely related to the product shape, and they are usually located on the parting surface or concealed areas of injection molded parts. Their spatial morphology is complex, their dimensions are tiny, and they are often surrounded by other structural features, posing special challenges for trajectory planning of robotic arms. Reasonable trajectory planning not only affects cutting efficiency but also directly relates to sprue quality and workpiece integrity.

2.1 Characteristics of plastic gate cutting trajectory

The gates of plastic injection molded parts are usually divided into various types such as direct gate, side gate, and pin gate, and their common characteristics are:

Spatial three-dimensionality: The gate is often not located in a single plane, requiring a three-dimensional space cutting trajectory; geometric complexity: The junction between the gate and the main body of the product often has a transition fillet, requiring precise tracking; accessibility challenge: The surrounding mold structure may limit the pose of the end of the robotic arm; thermal impact control: The path needs to be optimized to minimize heat accumulation.

2.2 Planning of plastic sprue cutting trajectory

Based on the aforementioned characteristics, the trajectory planning of the robotic arm must ensure that the cutting head maintains an optimal posture relative to the workpiece surface, keep the distance between the focusing lens and the workpiece surface constant, and guarantee that the laser beam remains perpendicular to the cutting surface at all times, in order to achieve uniform kerf quality. For particularly complex gate geometric features, it is often necessary to discretize complex trajectories into multiple simple line segments and arcs. Through the continuous path control function of the robotic arm, smooth transitions can be achieved, avoiding inconsistent cutting quality caused by sudden changes in speed.

3 Optimization of laser cutting process parameters

3.1 Quality records under different cutting parameters

The quality of CO_2 laser-cut plastic sprues is primarily influenced by a combination of laser parameters, motion parameters, and auxiliary gas parameters. These parameters exhibit complex interactions, collectively determining the final cutting quality. In-depth research on parameter optimization is crucial for achieving high-quality and high-efficiency sprue cutting.

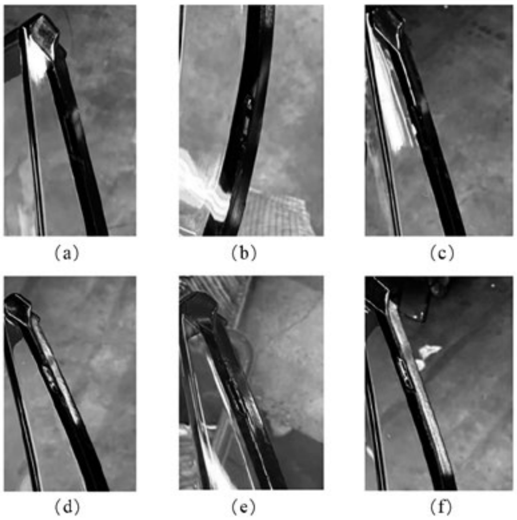

Figure (a) shows the robotic arm cutting at a speed of 300 mm/min with the cutting head's air blowing function turned off;

Figure (b) shows the robotic arm cutting at a speed of 300 mm/min, with a minute amount of cutting head blowing at 0.04 Pa;

Figure (c) shows the robotic arm cutting at a speed of 300 mm/min, with an increased blowing pressure of 0.1 Pa on the cutting head;

Figure (d) shows the robotic arm cutting at a speed of 150 mm/min with the cutting head blowing off;

Figure (e) shows the robotic arm cutting at a speed of 150 mm/min, with a minute amount of cutting head blowing at 0.04 Pa;

Figure (f) shows the robotic arm cutting at a speed of 150 mm/min, with a slight blow of cutting head at 0.1 Pa.

Figure 3 Comparison of laser cutting effects of the machine under different speeds and gas blowing conditions

In summary, under stable laser power conditions, the cutting speed and the amount of gas blowing have a significant impact on the cutting effect in laser cutting. When the cutting speed is too fast and the gas blowing is too strong or absent, the smoke generated by cutting will adhere to the surface of the product [as shown in Figure 3(a)-(c)]; when the cutting speed is slowed down and there is no gas blowing, the cutting effect will have a wavy appearance, and smoke will adhere to the surface of the product [as shown in Figure 3(d)]; when the cutting speed is slow and the gas blowing is increased to 0.1 Pa, the smoke generated by cutting will adhere to the surface of the product [as shown in Figure 3(f)].

3.2 The influence pattern of cutting parameters on quality

Based on laser cutting theory and experimental research, the influence of key process parameters on the cutting quality of plastic sprues is as follows:

Feed rate is the primary factor determining the cutting depth and the width of the heat-affected zone (HAZ). When the feed rate increases from 150 mm/min to 300 mm/min, the cutting depth exhibits a significant linear decrease trend, while the width of the heat-affected zone decreases from 1.2 mm to 0.5 mm. For typical plastic sprues (thickness 2~5 mm), a moderate feed rate (150~300 mm/min) is usually required to balance penetration depth and heat-affected zone control.

Laser power is a crucial factor affecting cutting capability. The 250 W Iradion CO2 laser can be continuously adjusted within the range of 50~250 W, accommodating the cutting needs of various plastic materials. For common plastic sprues with a thickness of 2~3 mm, the optimal power range is 150~220 W. Too low a power can lead to incomplete cutting, while too high a power can cause excessive vaporization of the material, resulting in a wide cutting gap or even burning and carbonization.

Pulse frequency and duty cycle have a significant impact on the control of the heat-affected zone. The Iradion laser supports pulse frequency adjustment from 1 to 150 kHz, and pulse modulation can effectively reduce heat accumulation. For heat-sensitive materials (such as PMMA and PC), using a high-frequency, low-duty cycle pulse mode can reduce the width of the heat-affected zone by approximately 30%.

Gas pressure has a significant impact on the cleanliness of the kerf and the heat-affected zone. High-pressure gas (3 Pa) can effectively remove carbonized residues from the kerf, reducing the thickness of the carbonized layer on the cut edge by 20%. However, excessive pressure can lead to lateral splashes of the melt during low-speed cutting, reducing the kerf quality score. Generally, it is recommended to use clean and dry compressed air or nitrogen at 2~3 Pa.

The focal position directly affects the energy density and the shape of the cut. For plastic cutting, the focal position is typically set 0.2~0.5 mm below the workpiece surface to achieve a uniform upper and lower cut. For sprues on three-dimensional surfaces, the focal position can be adjusted in real-time through an automatic focusing system to ensure consistent cutting quality. Additionally, the stability of the nozzle height is crucial for maintaining cutting quality.

3.3 Vision-based quality monitoring system

To achieve real-time monitoring of cutting quality, the system integrates a visual inspection module that captures images of the cutting area through an industrial camera and analyzes the following quality indicators:

Heat-affected zone width: Identify the carbonized area through color features; kerf width: Measure the geometric dimensions of the kerf; surface quality: Evaluate the condition of the cutting surface based on texture analysis. The vision system forms a closed loop with the control system, automatically adjusting process parameters when quality deviations are detected to ensure consistency in cutting quality.

3.4 Quality evaluation system

To objectively evaluate the quality of gate cutting, a comprehensive evaluation system has been established:

Section quality: By conducting macro and micro observations of the cut section, assess roughness, degree of carbonization, and slag adhesion; Dimensional accuracy: Measure the deviation between the actual cutting contour and the theoretical contour, including kerf width, angular deviation, etc.; Mechanical properties: Test the material strength near the cutting area and evaluate the impact of laser cutting on material properties. Through the above evaluation system, cutting quality under different parameter combinations can be quantitatively analyzed, providing data support for process optimization.

4 Application cases and result analysis

To verify the practical effectiveness of using a FANUC robotic arm to drive a CO_2 laser for cutting plastic sprues, an automotive rear tail light assembly was selected as the experimental subject. The assembly is made of ABS plastic with an average wall thickness of 2.5 mm and features 12 sprues distributed on a complex three-dimensional surface, making it difficult to ensure consistency with traditional cutting methods.

4.1 Experimental setup

The experiment utilized the aforementioned system configuration: a FANUC M-20iA robotic arm paired with a 250 W Iradion CO_2 laser, featuring a focused spot diameter of 0.2 mm and using dry compressed air (pressure 2.5 bar) as the auxiliary gas. The ROBOGUIDE software was employed to import the dashboard CAD model, automatically extract the gate contour, generate the initial cutting path, and subject it to trajectory optimization algorithm processing.

The experiment was conducted in groups for comparison:

Group A: Traditional manual cutting (skilled workers using specialized trimming scissors);

Group B: Robotic laser cutting (fixed parameters: power 200 W, speed 100 mm/min);

Group C: Robotic laser cutting (optimized parameters: power 180 W, speed 150 mm/min, pulse frequency 50 kHz).

Each group processes 20 samples, with evaluation indicators including: single-piece processing time, gate residual height, surface roughness, heat-affected zone width, and product pass rate.

4.2 Results and analysis

The experimental results show that robotic laser cutting is significantly superior to traditional manual methods in terms of gate treatment quality. The specific performance is as follows:

In terms of processing efficiency, the average processing time for a single piece in robotic arm laser cutting (Group C) is 7.8 s, significantly lower than the 22 s required for traditional manual cutting, representing an efficiency improvement of approximately 64.5%. This is primarily attributed to the high-speed movement of the robotic arm and the instantaneous action of the laser, while eliminating the time required for manual positioning and adjustment.

In terms of cutting quality, the average height of gate residue in the laser cutting group was 0.04 mm, achieving a level of almost no residue, while the average in the manual cutting group was 0.18 mm. The surface roughness (Rz) of laser cutting was 6.5 μm, significantly better than the 14.2 μm of manual cutting. The gate surface roughness improved by about 54%, providing a surface texture closer to the product body.

Heat-affected zone control: Under optimized parameters, the width of the heat-affected zone in laser cutting is 0.32 mm, with a uniform boundary, whereas the fixed parameters result in a width of 0.48 mm, indicating the effectiveness of parameter optimization in heat control. Although manual cutting has no heat impact, it suffers from significant stress whitening and microcracks.

4.3 System performance analysis

The FANUC robotic arm laser cutting system exhibits the following outstanding advantages in plastic gate processing:

High trajectory accuracy: Through the use of small circle accuracy software and visual zero-point correction technology, the system achieves a trajectory accuracy of ±0.1 mm on complex three-dimensional trajectories, ensuring precise tracking of the gate contour. Actual measurements show that the roundness error of the Φ8 mm circular gate is less than 0.15 mm.

Excellent flexibility: The hollow arm of the robotic arm perfectly complements the light-guiding arm, enabling built-in optical path, greatly reducing motion interference and ensuring cutting flexibility. The same system can handle sprues of different product models, with a switching time of only a few minutes.

Stable quality output: The TCP speed output function ensures real-time matching between laser power and cutting speed, eliminating inconsistencies in kerf quality caused by speed variations. Experimental data shows that the quality consistency of the optimized parameter group is significantly higher than that of the fixed parameter group, with a 70% reduction in intra-batch quality fluctuation, and the product pass rate increased from 82% to 98.5%.

Collision protection capability: During the experiment, accidental positional deviations were simulated. The magnetic anti-collision design effectively prevented equipment collision damage, with an average recovery time of no more than 5 minutes, significantly reducing potential downtime.

5 Conclusion

This study successfully developed a plastic gate cutting system based on the FANUC M-20iA robotic arm integrated with a 250W Iradion CO_2 laser, and verified its feasibility and superiority in industrial production. Through hardware integration, algorithm optimization, and process parameter regulation, the system effectively solved the problems of insufficient precision, low efficiency, and unstable quality faced by traditional gate removal methods. With continuous technological improvement and cost optimization, the technology of cutting plastic gates using a 250W Iradion CO_2 laser driven by a FANUC robotic arm is expected to become a standardized solution for post-processing of plastic products, promoting the development of the plastic manufacturing industry towards intelligence, efficiency, and high quality.