Revolutionizing automotive hot forming parts manufacturing: Unleashing the potential of TRUMPF 5-Axis 3D cutting machine TruLaser Cell 8030 through automated loading and unloading

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In the dynamic landscape of contemporary automotive manufacturing, the integration of cutting-edge technologies has become imperative to enhance efficiency and precision. This article examines the transformative impact of the TRUMPF 5-Axis Machine TruLaser Cell 8030, emphasizing its role in revolutionizing manufacturing processes, particularly through automated loading and unloading operations. The investigation encompasses a detailed analysis of key features for automation, such as X-Blast, ObserveLine Comfort and Professional, Smart Optics Setup Basic/Comfort, Automation Interface Professional, and the Machine Status Interface (OPC UA). Furthermore, it explores the machine's adaptability in diverse automation scenarios, from single-machine automation to interconnected systems.

Keywords: Automation; X-Blast; ObserveLine Comfort & Professional; Smart Optics Setup Basic/Comfort; Automation Interface Professional; Machine status Interface (OPC UA).

1. Introduction

The automotive industry is increasing adoption of laser technology in the production of hot-forming parts. This shift encompasses a range of laser-based processes, such as uncoiling with 2D laser blanking, laser ablation, Tailor Welded Blanking (TWB) and Patchwork welding, 3D laser trimming & hole cutting, as well as laser softening and laser joining, tailored to meet the unique requirements of each component. Among these processes, the precision trimming and hole-cutting of complex three-dimensional parts using 3D five-axis laser cutting machines stand out as pivotal advancements. These sophisticated techniques offer remarkable benefits, including accelerated production cycles and reduced manufacturing costs. Consequently, the integration of 3D five-axis laser cutting machines has become indispensable in automotive production facilities, driving innovation and enhancing efficiency in the fabrication of intricate automotive components.

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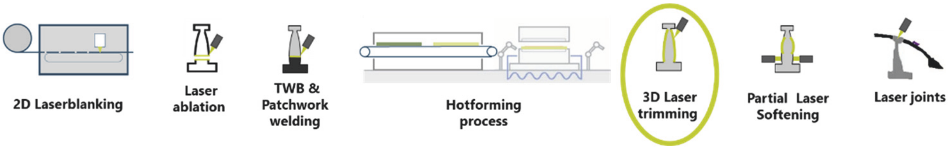

Fig. 1. Automotive Hot-Forming Parts Production Process and Key Laser Application Processes

Incorporating automation systems, particularly employing robots for loading and unloading, into the process of 3D laser cutting using 5-axis laser cutting machines presents a versatile solution to various contemporary challenges and concerns. Within the manufacturing environment, safety emerges as a paramount issue, compounded by hazards such as noise, heightened temperatures from hot forming ovens, particularly exacerbated during summertime operations, airborne particulate matter, and the manipulation of heavy workpieces. The scarcity of skilled operators willing to operate under such conditions is increasingly pronounced, accentuated by escalating labor costs. Furthermore, the turnover rate among operators remains high, precipitating inconsistencies in production quality and hindering uniformity. Automation obviates the necessity for scheduled breaks, shifts, or holiday periods, ensuring uninterrupted operations and maximizing machine production capacity, thereby optimizing hourly throughput rates. Moreover, automation facilitates seamless data acquisition and analysis, streamlining integration with Enterprise Resource Planning (ERP) and Manufacturing Execution Systems (MES), thereby facilitating data-driven decision-making and the refinement of manufacturing processes. The inherent advantages of automation in addressing these challenges are readily discernible.

To make the most of automation and improve safety, productivity, and quality, as well as to ultimately realize economic value for enterprises, it's vital to equip machine tools with a range of features. This research will use TRUMPF 5-axis machine tool TruLaser Cell 8030 (Fig. 2) as an example to explain the essential setups, functions, and technical know-how needed for smooth and reliable production in cooperation with robots for automated loading and unloading. By fully capitalizing on the capabilities of machinery, this approach endeavors to generate added value within the production workflow is the goal.

Fig. 2. TRUMPF 5-axis machine tool TruLaser Cell 8030 [1]

2. Automation Concept – Single Machine and Laser Line

The design of automated loading and unloading systems can take two main forms: Single Machine and Laser Line. The selection between these options is primarily influenced by several key factors:

- Production volume (parts/year): The expected annual production quantity determines the required throughput capacity of the loading and unloading system.
- Cycle time per part: The time needed to process each part affects the speed and efficiency of the loading and unloading process, how many robots are needed and the type selection.
- Part characteristics (size, weight, stiffness): The physical attributes of the parts being processed influence the design of handling mechanisms, tooling, grippers.
- Preference: Single piece flow vs. lowest cycle time: The desired production flow strategy—whether prioritizing continuous flow or minimizing cycle times—affects the layout and configuration of the loading and unloading system.
- Logistics/container requirements: Considerations for material handling, storage, and transportation within the production environment impact the design of the loading and unloading system, incl. AGV for material logistic between different workflow (e.g. oven, presser, stock etc.).
- Layout requirements (footprint): Available floor space and layout constraints dictate the physical arrangement of equipment and workstations.
- Hybrid (manual & automatic) or pure automatic mode: The decision to integrate manual labor alongside automated processes or a fully autonomous system influences system complexity and efficiency.
- Post-process requirements: Additional processes such as quality control inspections may need to be integrated into the loading and unloading system design.

The specific design of Single Machine and Laser Line loading and unloading systems concepts are illustrated in the accompanying diagrams.

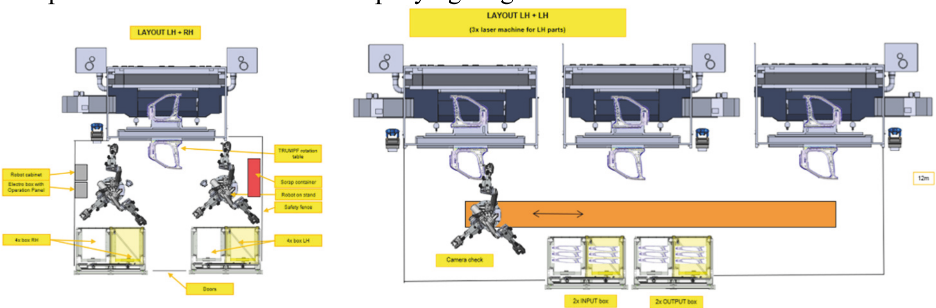

Fig. 3. TRUMPF Automation Concept – Single Machine (left) and Laser Line (right)

Single machine is usually used for parts with short cycle time (<45s) as manual labor for loading and unloading process is time tight. The laser line is usually used for parts with long cycle time (>160s) so that the robots can work between multiple machines with rail.

A time study is required to design a concept that can maximize the robots and machine working capacity.

3. New Challenges and Requirements in Automated Loading and Unloading

The use of automated loading and unloading with 5-axis laser cutting machines is still relatively new among major manufacturers and users in the world. The main challenge is ensuring stable production and accurate parts without human intervention, relying heavily on the machines themselves. Another challenge is establishing smooth communication between the machine and robotic arms. This requires compatibility with the machine's interface and software systems to enable seamless operation. Additionally, there's a growing need for production managers to monitor processes remotely and manage quality effectively. These aspects are critical for successful automation. The following section will delve into how the TruLaser Cell 8030 tackles these new challenges and meet these requirements.

3.1. *Stable Production Process*

- X-Blast Cutting Nozzle

During laser cutting process, machines are generally able to deliver good cutting results at high machining speed. However, when machining complex 3D workpieces. Challenges arise when critical parameters, like the nozzle-workpiece distance and laser nozzle position, cannot be consistently or precisely maintained due to unfavorable spatial configurations. This may lead to quality losses, especially when cutting workpieces at corners or angles, resulting in (micro) ridges or slugs. Additionally, the risk of cutting head collisions rises with increased machining speed and reduced distance between the nozzle and workpiece. [2] Human workers can manually handle the challenges such as polishing burrs and quickly and easily solving collisions on site, automation systems must solve these problems with minimum human interaction. The patented X-Blast technology from TRUMPF offers a solution by addressing challenges. The increased distance of the X-Blast technology reduces the risk of collisions when cutting 3D parts by a factor of around 10. In addition to the significantly increased robustness, the area along the laser beam with good cutting properties is doubled, which increases the efficiency and reliability of automated cutting processes.

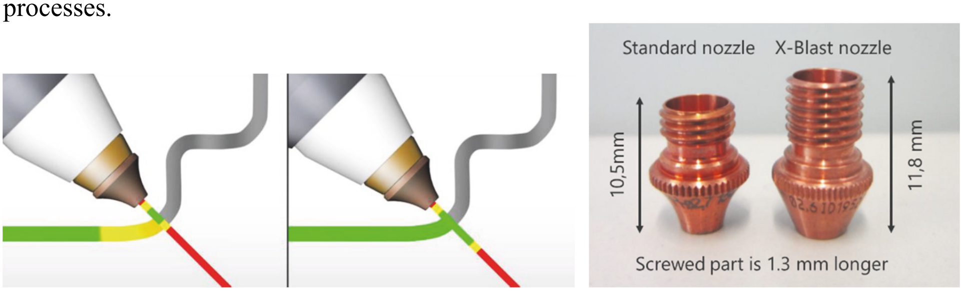

Fig. 4. Cut quality, depending on the zone along the laser beam of the standard nozzle (left) and the X-blast nozzle (right). Cutting quality decreases from green to red

By optimizing the internal contour of the nozzle to optimize the flow, with high momentum, good uniformity, and a tidy boundary as well as low turbulence and energy loss, the dimensions of the stable, convergent, and divergent sections in the supersonic nozzle must be correctly designed and accurately calculated based on the gas dynamics (Fig. 5). The gas jet is more parallel over a wide range. In addition, the energy loss at the nozzle outlet is reduced and the flow velocity is doubled, so that the cutting quality is drastically improved, and the stability of the production process and lifetime of nozzle is increased by minimizing collisions. [3]

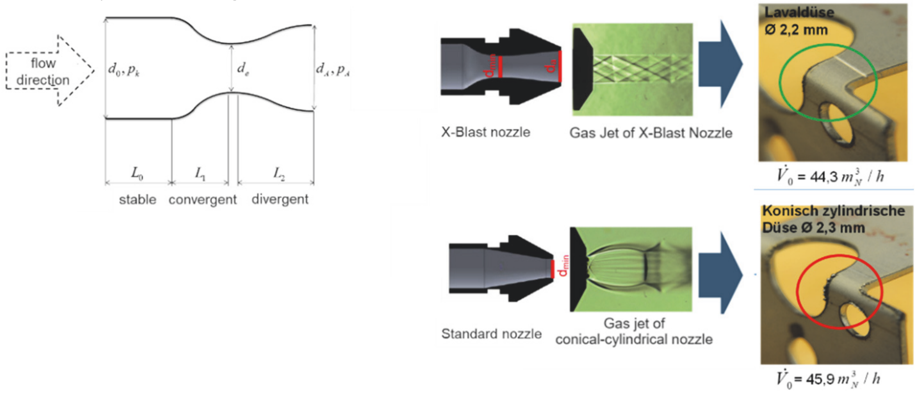

Fig. 5. Cross-section diagram of a supersonic X-Blast nozzle and its three key design sections (left) Comparison of the gas jet generated by the standard and X-Blast nozzle with cutting sample (right) [2]

It is not possible to achieve a higher quality with a standard nozzle with higher nozzle-workpiece distance, normally burrs and slugs have to be polished manually. With the patented X-Blast technology and laser technology table as a start parameter sets from TRUMPF, the cutting quality can be quickly satisfactory without further post-processing (Fig.6).

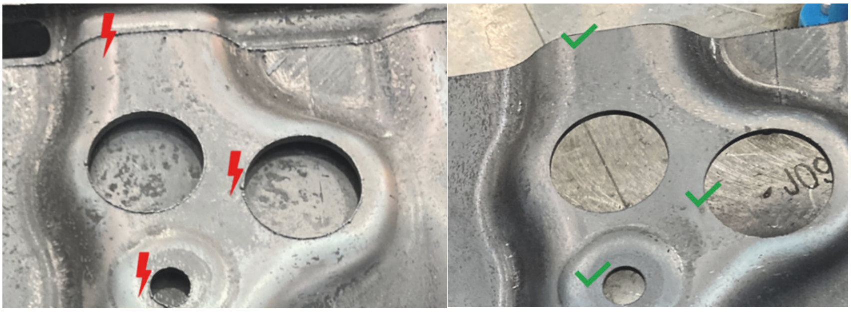

Fig. 6. Real parts at an automobile manufacturer, Standard nozzle cutting with another machine brand (left) burrs and slug are obvious, X-Blast cutting with TRUMPF Machine no post-processing needed (right)

Therefore, achieving good cutting quality without the need for post-processing, e.g. grinding or polishing is an essential prerequisite for automated loading and unloading. The goal of automation systems is to achieve high efficiency and quality production. If grinding is required during the production process, manual intervention is needed, leading to decreased production efficiency and potentially increased costs and time. Hence, to ensure the smooth operation and continuous production of automation systems, it is preferable to avoid the need for grinding. This implies that when designing automation systems, measures such as optimizing cutting parameters, designing reasonable process flows, and selecting appropriate cutting machines should be considered, thereby enhancing production efficiency and product quality.

3.2. *High Part Accuracy Requirements*

- ☐ ObserveLine for non-fallen slugs detections
- ☐ Smart Optics Setup for calibration

In real production scenarios, cutting slug waste may persist in finished parts for various reasons. Many users resort to "hedgehog" inspection tool (Fig.7 left) for manual checks to ensure all holes have been cut through. The process is time-consuming and labor-intensive. However, the TRUMPF ObserveLine optical measuring procedure offers a swift and automatic solution to this problem. This patented system meticulously examines every contour to determine whether slug waste have fallen out, providing a yes/no indication to the system. It can detect slug waste also at angles (Fig. 7 right), identify holes with diameters less than 4 mm, and complete one measuring cycle in just 65 ms—four times faster than capacitive measurement. Checking the contours to ensure that the waste has been removed no longer requires manual intervention, enabling high level of automation.

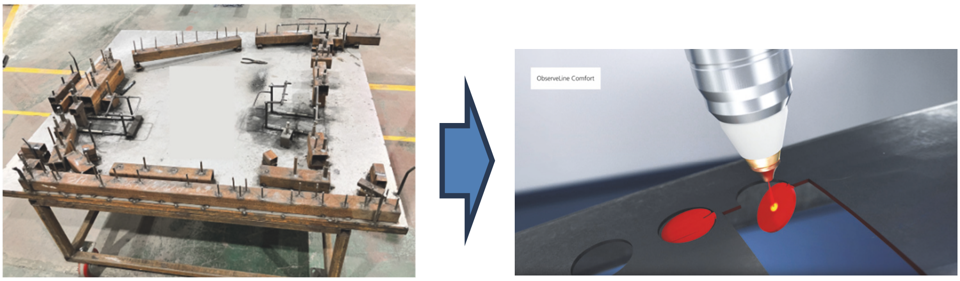

Fig. 7. "Hedgehog" inspection tool, need to manually put the parts on it for recognition of non-fallen slugs (left) TRUMPF integrated measuring system ObserveLine can automatically detect non-fallen slugs (right) [1]

Furthermore, ObserveLine Professional enhances cutting accuracy by addressing the issue of minor nozzle collisions, which can cause imperceptible misalignments of cutting optics, leading to increased scrap and costs. This optical measuring procedure regularly checks machine positioning accuracy at user-defined intervals, without requiring refitting and with minimal impact on cycle time. It automatically detects incorrect positioning, reducing the number of rejects. It also assures machine accuracy through a patented system for automatic and fast checking of axis system accuracy, with individually adjustable frequency and no sensors required in the working area. Effect on cycle time (each 100th part is tested): 0.02 seconds. With this function can maximum safety, accuracy and productivity of automation production.

The Smart Optics Setup (Fig. 8) offers a convenient solution for calibrating and readjusting machine accuracy when needed. Featuring a swiveling test bench within the working area, this setup streamlines typical setup activities, enhancing speed, ergonomics, and safety. The station's end position is monitored, and tests can be automatically initiated using macros. Moreover, it enables automated measurement and transfer of measured values from the test sheets to the control system. Overall, this system provides a safer, easier, and faster alternative to manual measurements, ensuring efficient machine calibration and readjustment.

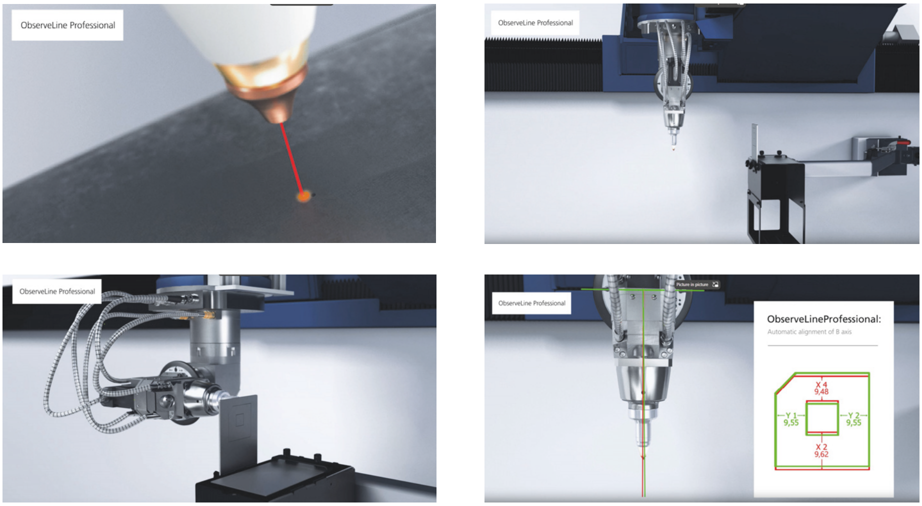

Fig. 8. Calibration and Readjustment: If machine accuracy deteriorates or adjustments are required, use Smart Optics Setup to cut test sheets and readjust the machine accordingly [1]

3.3. *Connectivity and communications*

- ☐ Automation Interface Professional
- ☐ Machine status Interface (OPC UA)

To establish connections with robots, TRUMPF offers the standard package known as "Automation Interface Professional". This package includes a flexible digital interface with BUS protocols, including Ethernet/IP, ProfiNet, and ProfiBus. It is designed for use with a rotary table for loading and unloading workpieces, enabling automated processes with a robot. Each production place typically requires one component, with a rotary table serving two fixtures. The interface facilitates seamless communication with the robot through a single handshake, ensuring efficient transfer of workpiece number pulses and beam-on signals to higher-level controls for further processing. Additional functionalities include support for tasks such as empty running and approach of the robot, with the capability for restart after abort in defined machine statuses. Moreover, the interface supports digital signal exchange for secure signals like emergency stop and safety area enablement.

Moreover, TRUMPF can equip with OPC UA provides several benefits for automation loading and unloading in production environments:

OPC UA is a standardized industrial communications protocol, ensuring compatibility and interoperability between different automation devices and systems. This standardization simplifies integration and communication across the whole production environment.

OPC UA enables data exchange over network connections, allowing seamless communication between machines, sensors, and control systems involved in the loading and unloading processes. This facilitates real-time monitoring, control, and coordination of operations and production status.

OPC UA provides easy access to important machine and laser parameters, as well as their current states. This enables operators to monitor and adjust settings remotely, efficiently, optimizing performance and productivity.

Also, OPC UA is suitable for various applications in automation loading and unloading, including controlling automation and production lines, documenting and tracing component history, implementing predictive maintenance strategies, storing NC programs on servers, and evaluating operating data displayed on dashboards.

Fig. 9. OPC UA[*] Logo [4]

3.4. *Transparency in production*

- ☐ Smart View
- ☐ Details about production numbers
- ☐ Predictive machine maintenance
- ☐ Quality proven production (NC program history)

Transparency in production is crucial for production managers when operating machines with automation. They require clear visibility into the status of operations and production. TRUMPF Industry 4.0 Starter Package offers mature and completer solution in this regard:

- Equipment overview
  - Status display via live statuses
  - Central, cross-plant status overview
  - Location independent access
- Messages and detailed status information
  - Status details, messages and recommendations for action
  - Evaluations of equipment usage
  - Create service cases directly in Smart View

[*] The OPC Unified Architecture (UA), released in 2008, is a platform independent service-oriented architecture that integrates all the functionality of the individual OPC Classic specifications into one extensible framework. [4]

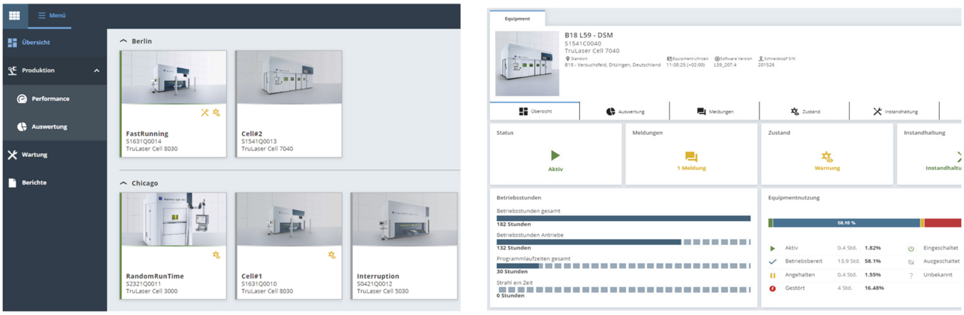

Fig. 10. Dashboard of Equipment overview (left) and Detailed status information (right)

Program runs of the laser system

- Quick overview of the runs of previous shifts
- Identification of gaps to increase productivity
- Comparison of productivity between machines

- Program changes and NC program history
  - Tracking of changes to the machine program and laser technology tables
  - Supports the documentation for quality assurance

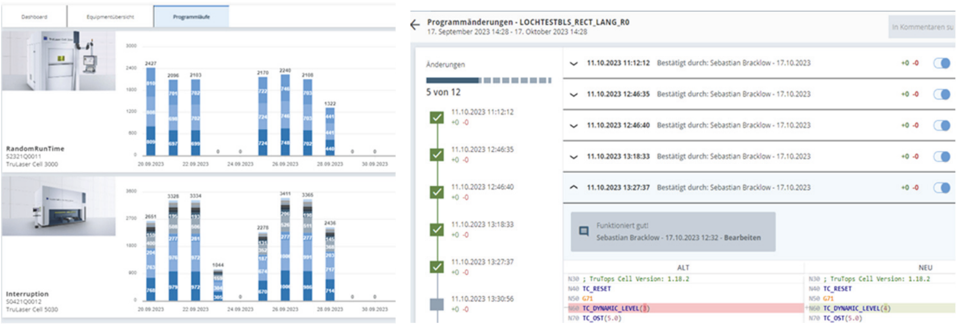

Fig. 11. Dashboard of Program runs of the laser system (left) and NC program history (right)

- Remaining time display
  - Display of the program runs and the remaining runtime of the current program and the current shift
  - Display of good parts, defective parts and aborted programs
  - Location independent access and overview through all equipment
- Run time analysis
  - Analysis of program throughput times
  - Display of min, max and average values within a defined time periode
  - Trend analyses

Fig. 12. Dashboard of Remaining time display (left) and Run time analysis (right)

- Energy and gas consumption analysis
  - Display of energy and gas consumption
  - Visualization of total values and analysis of consumption per program run / shift / etc.
- Condition Monitoring
  - Monitoring of laser systems and lasers by TRUMPF experts remotely
  - Predictive trend analysis through algorithms
  - Reduction of unplanned downtimes of machines
  - Proactive service/ maintenance/ repair case
  - Enhanced service preparation & pre-planning

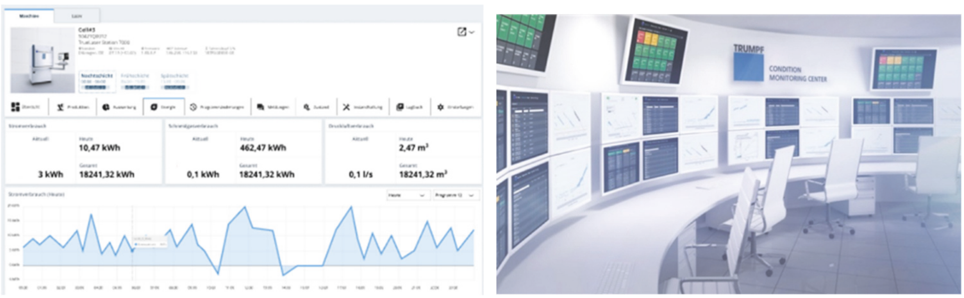

Fig. 13. Dashboard of Energy and gas consumption analysis (left) and TRUMPF Condition Monitoring Center (right)

Through the implementation of digital service products like Smart View and Condition Monitoring, the entire production process can be seamlessly transplanted and made more controllable for automation loading and unloading, can be effectively managed, optimized, and controlled, leading to increased productivity, reduced costs, and improved overall performance.

4. Summary and Outlook

In summary, the integration of laser technology, particularly through the utilization of 5-axis laser cutting machines, has revolutionized the automotive industry's production of hot-forming parts. These advancements encompass various laser-based processes tailored to meet the intricate demands of automotive component fabrication. Automation, particularly through the deployment of robots for loading and unloading tasks, has emerged as a crucial solution to contemporary challenges such as safety concerns, qualified labor shortages, labor cost increase and production quality inconsistencies.

The choice between Single Machine and Laser Line loading and unloading systems depends on factors like production volume, cycle time per part, part characteristics, production flow strategy, logistics requirements, available space, and the level of automation desired. Each system configuration offers distinct advantages suited to different manufacturing environments.

However, the adoption of automated loading and unloading with 5-axis laser cutting machines presents new challenges, including ensuring stable production processes and achieving high part accuracy with minimum human intervention. TRUMPF TruLaser Cell 8030 addresses these challenges through innovative technologies such as X-Blast for stable cutting processes and ObserveLine for high part accuracy requirements. These technologies mitigate issues like nozzle collisions, burrs and slug waste detection, enhancing production efficiency quality and stability.

Furthermore, connectivity and communication play a vital role in automation, with TRUMPF providing solutions such as Automation Interface Professional and OPC UA for seamless software & hardware integration and real-time production data exchange. Transparency in production is also crucial, facilitated by TRUMPF Industry 4.0 Starter Package, and offers functions such as Smart View and Condition Monitoring to empower and add value to the smart and digital factory.

Looking ahead, the continued advancement of laser technology and automation systems will further enhance efficiency, productivity, and quality in automotive hot forming parts manufacturing. As Industry 4.0 principles become more pervasive, the integration of digital technologies will enable even greater transparency, control, and optimization of production processes, paving the way for a more competitive and sustainable automotive industry.

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