PRODUCTION TECHNOLOGY AND PRODUCTION SYSTEMS

1 Introduction

The global COVID-19 pandemic continued to make its presence felt in 2022, with lockdowns and other measures to prevent the spread of the disease causing a major blow to economic activity. In addition, geopolitical circumstances resulted in adverse effects such as high material prices and disrupted logistics. Many other problems, such as global warming, and the decrease of the labor force, are also rearing their ugly head.

In the automotive industry, initiatives to achieve carbon neutrality have turned into more concrete activities, and there are more and more plans to introduce electric vehicles, which contribute to decarbonization. At the same time, the pace of advances in the functionality of vehicles representative of CASE is rising.

Addressing those issues in the context of automobile production activities involves a variety of production technology challenges. Unexpected circumstances such as shortages of parts supply or sudden changes in the labor force due to natural disasters or a pandemic are anticipated to arise again in the future. In the context of achieving carbon neutrality, differences in powertrains and vehicle structure between EVs and conventional internal combustion engine vehicles require effectively examining production lines for each type of vehicle. It is also essential to push for decarbonization in production plants as a whole, including the various manufacturing processes and common lines. Advances in vehicle functionality call for higher numbers of electronic and electric components that are becoming more sophisticated and offer ever more functions, increasing the complexity of on-site functional checks at production plants. Check methods are being revised to make the cycle faster. At the same time, the growing adoption of production technologies that make full use of digital transformation (DX) elements such as AI or virtual reality (VR) and their incorporation in production environments are reducing the burden on workers and helping to facilitate the work.

2 Vehicle Production Engineering (PE) Technologies

2. 1. Stamping

In addition to battery technological development, reducing vehicle weight is another crucial theme for increasing the cruising range of EVs, which contribute to carbon neutrality. Parts that use aluminum alloy materials (aluminum sheets) are seeing greater adoption, and approaches such as switching to thinner sheets made of ultra-high tensile strength steel are also becoming more common.

Aluminum sheets have poorer formability than steel sheets and involve serious issues such as poor accuracy or surface distortion caused by elastic recovery (springback) after forming. Using them in hoods, doors, and other parts requiring a high degree of styling reproducibility calls for technologies that can accurately predict and correct forming issues at the digital stage. Manufacturers continue to work on increasing the precision of sheet forming simulations by adding techniques such as taking friction variation during forming into account or raising the accuracy of the material models. Recently, using a 3D scanner to quantitatively evaluate the appearance of the styling surface of stamped parts has made it possible to achieve a high level of correlation with simulations.

The ultra-high tensile strength material primarily used in frame components is achieving even higher levels of strength. Cold-stamped 1.5 GPa class material has been developed and is starting to be used in mass production vehicles. Technologies that secure die rigidity and durability at the digital stage through the development of special forming methods, and the use of techniques such as rigidity simulations, complement improvements in sheet forming simulation precision and make a major contribution to the application of the material.

In conjunction with reducing CO_2 emissions during product use, decreasing emissions during manufacturing is critical. Activities such raising material yield through shallow drawing and maximizing scrap material use, decreasing the number of processes, reducing the weight of stamping dies and shortening lead times for die manufacturing are being carried out as in the stamping processes.

The declining birthrate and decrease in the labor force represent major issues requiring as much attention as environmental measures. The stamping die manufacturing stage includes surface finishing at the micron level and areas dependent on highly skilled craftsmanship. It will become necessary to develop technologies to improve workplaces through automation and ergonomic approaches such as building know-how and skills databases, or using AI to remove dependence on skill.

2. 2. Welding

The intensification of initiatives to achieve carbon neutrality are making the need for electrification and weight reduction even more important. With electrification, automobile components consist of parts such as motors, inverters, and batteries. Copper joining for the copper in motors and inverters, both copper and aluminum alloy joining in batteries, and aluminum joining technologies for the installation of cases for large capacity batteries exceeding 70 kWh are all essential.

In copper joining, laser welding technology that uses a laser oscillator to intensify the output of green and blue wavelengths, which have a high optical absorption ratio for copper, is garnering attention. The structure of aluminum battery cases is constantly evolving, and various joining technologies, including arc, laser, spot and mechanical welding are employed.

The electrification of vehicles is making it ever more important to reduce the weight of vehicle bodies. However, compared to the expanded use of aluminum seen from 2012 to 2016, the proportion of aluminum use has been staying roughly the same, or even decreasing, with higher strength steel sheets becoming the preferred solution. High tensile strength steel has a high content of carbon and other additive elements, making difficult to ensure weld quality because the segregation those elements make welds prone to becoming hard and brittle Therefore, the primary joining technology used is low-resistance spot welding, which enables control of the composition and structure of the welds and of the heat-affected zones by manipulating electrical current patterns.

Aluminum is used in a subset of models. The application of the best material for a given location is making multi-material use more prevalent, making joining technology for dissimilar materials necessary. Although various research institutions are carrying out research and development on thermal processing-based joining technologies, none have reached the practical application level. The mainstream mechanical joining technologies are self-piercing rivets (SPR) and flow drill screws (FDS).

The focus on carbon neutrality is expected to continue to increase the importance of electrification and weight reduction in years to come. Establishing joining technologies for aluminum and copper, as well as for dissimilar materials is essential, and it will be necessary to keep close track of technological trends on a global level.

2. 3. Plastic Molding

The use of plastic materials in various automobile parts is expected to increase remarkably due to their contribution do weight reduction and design. Broken down by part, trends in plastic use in automobiles show that CFRP, which is half the weight of steel, is used in some vehicles for the hood, roof, or other outer panels. Similarly, plastic is used to realize complex shapes that cannot be formed using steel to respond to design needs not just in bumpers, but also in fenders and back doors. In newer EVs, the ability to dispense with the air intake required by conventional gasoline vehicles is leading to changes in the design of the area ranging from the bumper to the grille. Selecting material that allows laser penetration is becoming more important as the pursuit of automated driving also increases the number of sensors.

In interiors, improvements in connected cars or the in-vehicle environment have brought about large information displays in instrument panels, and integrated forming is increasingly applied to touch panels and other device parts. The transition from steel to plastic for the purpose of reducing weight is also seen in engine parts, where it also helps increase fuel efficiency. Until now, plastic use centered around the air intake system or other locations with a low heat resistance temperature. However, advances in materials are anticipated to lead to the use of plastics for high temperature parts.

Research on transitioning to plastic in batteries, which are crucial to EVs, is underway. Materials with enhanced flame resistance are being developed to enable the use of plastic for battery cases, and plastic materials are already used for the upper case of some battery cases. Injection molding, the main processing method used for plastic materials, increasingly makes use of injection foam molding to reduce weight. At the same time, the film insert and two-color molding decorative processing methods are seeing broader use for the purpose of improving design versatility. For the CFRP composite material, hot press molding processing methods ranging from the RTM method that involves injecting thermosetting resin into the carbon fiber to, more recently, progress in the research and development of carbon fiber reinforced thermoplastics, are drawing attention. Plastic processing facilities automation centering on injection molding machines and extending to the peripheral device and product inspection secondary processes is becoming more common, and the introduction of comprehensive facilities that integrate AI into preventive maintenance and quality control is expected to expand.

The anticipated continued increase in the number of plastic parts also presents challenges from the standpoint of current carbon neutrality and recycling efforts. Carbon neutrality initiatives will require not only recovering plastic from nanocellulose fiber (NCF) plant-based material as well as the automotive shredder residue (ASR) retrieved from dismantled vehicles, but also blending materials recycled from the market and increasing the recycling rate.

2. 4. Paint

In automobile painting processes, achieving carbon neutrality and the SDGs is being pursued by complementing approaches that reduce the energy consumption of conventional technologies with ongoing technical development spurred by production system innovations such as new paint hardening processes that significantly decrease the number of steps, or efforts to make the painting booth itself, which is the largest emitter of CO_2 in the painting process, redundant.

One development in paint hardening processes eliminates the separate plastic painting step by lowering the baking temperature for the top coat to simultaneously paint the steel sheet vehicle body and plastic parts such as the bumper. That technology has been implemented and is coming into use in mass production. Eliminating drying furnaces for sealers and undercoats, as well as lowering the drying furnace temperature for electrodeposition baking is being studied for the same purpose. Electrodeposition drying furnaces handle many different materials as they notably serve not only bake the paint, but also to bake harden the vehicle steel sheets as well as to bake the reinforcement materials attached in the preceding vehicle body process. Consequently, studies to lower the temperature of the electrodeposition drying furnace require both communicating that need to the vehicle body process, steel sheet manufacturers, and parts manufacturers, and laying out a course of action for those activities. All of those technologies are suited to the two- and three-tone outer panel application of multitone colors users have been strongly favoring. This a technological field can offer new value and is therefore widely needed in the industry.

Until now, the automation of processes had focused on reducing manufacturing costs and improving quality. However, the need to address labor shortages is stimulating the development of automation technologies enabling robots and equipment to reproduce inspections, touch-up corrections, and other difficult tasks that rely on human senses and extensive experience. Recently, the use of AI algorithms in software has resulted in dramatic progress in the performance of such technologies. Additionally, promoting the automation of quality inspections has made it possible to acquire information on the total quality of products, raising expectations that it can be used to enhance quality control technologies.

2. 5. Vehicle Assembly

Vehicle assembly, the final process in vehicle production, consists of attaching many different parts to the fully painted body, and performing quality assurance checks. A typical vehicle assembly line involves the mixed production of several models and specifications and represents a process that is highly dependent on people due to the need to perform a variety of complex tasks such as bolt tightening and fitting, or assembly involving soft parts such as harness routing or plastic parts. In addition, component parts are procured from a large number of partner companies and involves a larger scale supply chain than other processes. Recent changes in business conditions have brought two major challenges to the fore with respect to the structural characteristics of these vehicle assembly processes.

The first is reducing dependence on people. Vehicle electrification prompted by growing environmental awareness, along with improved automated driving technology functionality aimed at providing added value, have resulted in more sophisticated and complex vehicle structures and functions. Those structures and functions raise the issues of establishing new quality assurance technologies and acquiring new skills, and those issues are entangled with the labor shortage problem caused by the declining birth rate and aging of the population. The second challenge is ensuring productivity in low-volume production of multiple models. Diversifying customer needs have increased the need for the mixed production of multiple models on the same assembly line, making it a challenge to maintain mass production system competitiveness in terms of quality, cost effectiveness, and delivery times—in short, productivity—at a high level. Measures to take on these challenges are discussed below.

Dependence on people is being tackled through measures such as automation or assistive devices to support heavy manual labor, improved work posture based on module subassemblies, and the use of AI image processing to check part specifications. Those approaches reduce both dependence and the burden on people, and foster a staff friendly workplace. Fully taking productivity into account at the vehicle structure design stage is effective for the low-volume production of multiple models, and this approach works hand-in-hand with the use of digital technologies typified by virtual reality. At the same time, process preparation requires a gradual transition to EV production facilities while continuing the production of existing vehicles, which calls for strategic process design.

Advances in vehicle intelligence and connected technologies involve communication with the electronic control unit installed in vehicles. Consequently, there is a need for to update equipment that writes data to vehicle electronic components, adjusts sensors, and runs diagnostics, as well as to establish initiatives compliant with regulations in various countries to reduce the attendant cybersecurity risks.

Lastly, geopolitical risks have also recently become prominent. Vehicle assembly processes involve many manual labor steps and a large-scale supply chain. Keeping those processes competitive in the future will undoubtedly require process planning that enables flexible adaptation to fluctuations in production plans.

2. 6. Vehicle Inspections

The vehicle inspection process is responsible for verifying compliance with regulations in destination countries and guaranteeing uniform consistency with type designated vehicles, as well as for ensuring a high level of quality that meets customer demands.

Certified inspectors conduct the inspections based on the present vehicle type designation system.

In response to advances in AI and other inspection technologies, the Ministry of Land, Infrastructure Transport and Tourism (MLIT) issued a guideline for the automation of completion inspections in March 2021. The Ministry then published partial amendments to the *Type Designation Regulations for Motor Vehicles* and *Completion Inspection Implementation Regulations* in November 2021.

In establishing the criteria of having a system at least equivalent to a certified inspector, automatically stopping the line when an anomaly is detected, automatically recording results, as well as assigning a supervisor and defining clear management rules, MLIT has made it possible to conduct completion inspections without retaining certified inspectors.

Over the last few years, geopolitical and other risks have led to ongoing uncertainty concerning procurement and supply, resulting in continued production instability. As the labor force continues to decrease due to the declining birthrate and aging of the population, hiring and retaining certified inspectors with the proper qualification will become difficult. Automakers are therefore expected to intensify efforts to streamline completion inspections and make them more efficient to respond to such fluctuations swiftly and flexibly.

Automating inspections previously conducted by people also calls for storing inspection records electronically in a format suited to subsequent analysis. This means not only recording the results, but also linking related data via IoT to include data on inspection conditions and factors incorporated in upstream processes. Doing so is expected to help improve products and processes.

There has been a change in the way vehicles and services are used to provide a means of transportation for people no longer able to drive in countries and regions where aging and depopulation is accelerating due the concentration of the population in cities.

Given that next-generation driving support technologies and services such as ride sharing will continue to expand, building technologies capable of providing mechanical and quantitative assurance in bench tests not only in this area, but also in quality assurance for automated driving functions and connectivity, is viewed as essential to handling advanced technologies and improving their level of quality assurance.

3 Powertrain (PT) Production Technologies

3. 1. Casting

Casting, which shapes metal through heating and melting, is a manufacturing technology that is used to produce parts with a specific shape and plays a crucial role in automotive parts manufacturing.

The manufacturing industry, and notably the casting industry, is currently grappling with mechanization and environmental issues. Solving those issues will require various new technologies as well as the revamping of processes.

These days, reducing CO_2 emissions is being emphasized to combat global warming. Casting plays a major role in an industry seeking a path toward carbon neutrality. Both in general, and more particularly in the case of aluminum casting, the process is recognized as a way to reduce automobile weight, decrease CO_2, and contribute to carbon neutrality through material replacement.

The newer trend of ultra large casting technology significantly reduces the number of parts and shortens production processes by performing the integrated casting of part of a section of the vehicle body using ultra large casting equipment instead of using the traditional vehicle production processes that involve combining several stamped sheets. Among automotive industry-related businesses, that trend has led to an increase in companies such as Giga Press, which use new casting technologies.

Cast shapes that secure characteristics such as durability equivalence and impact absorption through topology analysis are also used in aluminum cast parts for automobile bodies to maintain conventional performance requirements as part of ongoing advances in reducing weight and cost.

Automobile weight reduction based on aluminum castings also contributes to raising EV efficiency and decreasing CO_2 emissions by downsizing and further reducing the mounted weight of the batteries. Casting will remain relevant for various usages. Applying new technologies such as AI and IoT to casting technology in the form of, for example, data acquisition through the monitoring of cast shapes or analysis methods for the acquired data, is anticipated to make product development faster and more efficient. Casting continues to be a promising carbon neutral process that reduces CO_2 emissions.

3. 2. Forging

With the intensification of initiatives to achieve carbon neutrality, the electrification of automobiles and attendant changes in manufacturing have created significantly different expectations for forging.

Electrification has brought about major changes in powertrains, which use many forged parts. The engine and transmission combination of the past has given way to the combination of motors and speed reducers, resulting in a shift in the main forged components. The increasingly prevalent need for downsizing and weight reduction to achieve longer cruising ranges while mounting a heavy battery has also been prompting the development of technologies such as hollowing, integration and higher strength. Even in terms of the vehicle as a whole, the use of high strength aluminum forged parts in suspension links and other examples of contributing to weight reduction through material substitution, as well as the adoption of other processes as alternatives, have become commonplace.

Forging uses a large amount of energy and can contribute to carbon neutrality in manufacturing in many areas. This has led to the implementation of initiatives encompassing previous, subsequent, and peripheral processes. Proposals include reducing the amount of material used through near net shaping, scaling down the machining process, adopting untempered steel, eliminating heat treatments that rely on work hardening, and even generating electricity from the large amount of waste heat, or switching to warm water. Other proposals, such as the electrification of forging facilities, reducing energy consumption, downsizing dies and jigs, or extending service life, revolve around peripheral technologies.

Digital technologies are increasingly used from the standpoint of reducing energy consumption. Greater simulation accuracy not only reduces the number of prototypes used, but also leads to suggesting more efficient processes such as proposing weight reducing shapes, or raising material yield. Initiatives to reduce energy consumption through methodical increases in efficiency such as incorporating IoT into production equipment and, for example, monitoring its status to create assembly lines that do not stop thanks to preventive maintenance, or achieving lines that monitor equipment conditions to prevent the production of defective products, are underway.

Outside Japan, local production and procurement is increasingly adopted to reduce transportation-related energy consumption. Making forged parts of uniform quality on a global scale requires training local staff, and digital technologies are used for this purpose as well. Even when training at remote locations is necessary, timely online guidance is increasingly possible through the use of electronic forms and manuals.

3. 3. Machining

The flexible processing lines easily adapted to variations in models and production volume used in machining have long consisted of general-purpose equipment to respond to sudden changes in product needs. However, as the global clamor for carbon neutrality becomes a concrete goal set by both countries and corporations, machined products themselves are liable to change considerably. This will make it necessary to introduce completely new methods, as well as to use highly efficient machining approaches that consume less energy.

Achieving significant improvements in engine fuel efficiency will require adding the special equipment of new methods to the existing flexible machining lines, as well as achieving stable quality at a low production cost even in relatively unfamiliar fields such as laser beam machining, thermal spraying, laminating & coating technologies, and the machining of new materials.

In terms of energy efficient machining, general purpose equipment still offers the possibility of improvements in areas such as higher efficiency, downsizing, weight reduction, and switching to airless systems, but will eventually reach its limits. It is therefore necessary to look into machining efficiency and highly efficient equipment. There are actual parts produced using a simultaneous multi-axis machining transfer center, which achieves a 32% reduction in energy consumption compared to machining the same parts using general-purpose equipment.

The visualization of the operating condition of the entire line, including conveyance offered by advances in Internet of things (IoT) technology, as well as more efficient production relying on data use to stabilize quality, also have plenty of growth potential.

Responding in an agile manner to changes in products themselves will require establishing concurrent production methods to shorten the time from design to mass production. High expectations are placed on the growth of digital technologies that will maximize production line efficiency in the shortest possible time by, for example, implementing a unified mechanism to immediately update on-site forms without error when an engineering change is made, or to carry out line layout design and load trials in a metaverse.

At the same time, reforms of work practices and diversification are leading to increased use of AI to reduce human burden in plant work sites. Replacing humans with the full automation of tasks requiring prolonged concentration, such as visual inspections, remains difficult at this time. However, AI-based decisions have now made it possible to decrease the burden on workers and reduce variations in decisions, leading to increased AI use in a support role. The scope of such applications is anticipated to continue to expand.

3. 4. Heat Treatment

Heat treatment is a process in which the appropriate amount of heating and cooling is applied to the parts that transmit the driving power in a vehicle, such as the engine, transmission, and final drive. This critical process is indispensable to reducing the size and weight of power units by enhancing their strength.

The spread of automobile electrification amid intensified initiatives to achieve carbon neutrality has increased the need for downsizing and weight reduction, as well as higher strength, and further raised expectations placed on the contribution of heat treatment. The heat treatment process emits a considerable amount of CO_2, and is subject to calls for improvements that will contribute to the carbon neutrality of the manufacturing sector.

Gas carburizing with oil quenching has long been used on gears and other drive system parts with high strength requirements. Vacuum carburizing has become more common since the 2000s. In vacuum carburizing, processing takes place at a lower pressure and, thanks to higher temperatures, at a faster rate. This significantly reduces the amount of carburizing (combustible) gas used, which in turn greatly decreases CO_2 emissions.

While this process requires caution in setting conditions and maintaining the equipment to avoid equipment problems caused by soot and prevent quality defects due to excessive carburizing, the absence of grain boundary oxidation during gas carburizing results in improved fatigue strength.

Initiatives to achieve even higher strength through material development, as well as combining the process with surface treatments or other peripheral technologies, are also being carried out.

In Europe, high-pressure gas quenching is increasingly used for its advantages in terms of part precision after heat treatment. However, the very strict manufacturing standards for equipment handling high pressure gas exceeding 1 MPa have impeded the widespread adoption of that technique in Japan. In the 2010s, the growing trend toward small modularization and the decreasing size of heat treatment lots made it possible to sufficiently quench parts even at gas quenching pressures of 1 MPa or less. The use of vacuum carburizing with gas quenching technologies is growing because it dispenses with quenching oil, which is a hazardous material, and uses small lots that can be automated in the machining line. Thanks to those excellent environmental, quality, and production characteristics, vacuum carburizing is anticipated to see expanded application.

In the field of heat treatment simulations, initiatives that work in conjunction with fluid analysis inside the heat treatment furnace to improve heat treatment conditions without actual prototypes, reduce the amount of combustible gas, and help decrease CO_2, are underway.

Heating in conventional heat treatment furnaces often relies on typical fossil fuel-based gas. However, efforts by equipment manufacturers to develop heating that uses renewable energy and highly efficient heat insulating material are expected to help get a step closer to carbon neutrality.

3. 5. Powertrain Assembly

These days, plans to launch EVs in the market are one of the more concrete activities in carbon neutrality initiatives, and electrification is also expected to become more common in the powertrain field as well.

At the same time, there is a need to respond to sudden fluctuations in production given the severe conditions of logistics disruption, semiconductor shortage, and high raw material prices caused by the pandemic or conflicts.

Against that backdrop, the labor environment is changing rapidly due to the declining birthrate and aging of the population, the decrease in the working population, the higher proportion of women, and the shying away from the manufacturing industry by young people. These factors combine with fluctuations in production volume to make stable production difficult, and made eliminating human error and creating people-friendly workplaces pressing issues in powertrain assembly plants, which rely primarily on human labor.

Additionally, the increased sophistication and complexity of products requires higher levels of skill than ever, and it is now urgent to both raise and transmit those skills.

One solution is the use of robots, and the latest robots are not limited to simple tasks. Highly-polished worker skills have been quantified and taught to robots that are assigned tasks requiring a high level of skill. In short, robots that perform the work of a professional are coming onto the scene.

Similarly, sensing, AI, and image recognition technology is starting to provide in-process quality assurance that is not dependent on the sense of a professional.

The coexistence of people and robots is also becoming more common as robots helping with tasks that are hard for people are bringing about the realization of an environment that facilitates the active participation of women or the elderly.

Measures aimed at improving production and energy efficiency and transitioning to electrification and renewable energy to achieve decarbonization are also diverse, and include the electrification of tightening tools and other instruments, a switch to LED lighting, and the application of electric power to on-premise transportation.

Despite the continued rise in demand for decarbonized vehicles, an impressive number of engines and transmissions is predicted to remain in use.

It will be more important than ever to combine the mass-production technology know-how accumulated over the years in the engine and transmission fields with the latest technologies in the electric unit field, as well as to build powertrain assembly lines that are both versatile and capable of producing powertrain units as a whole at a low-cost.

4 Digital Technologies

In automobile manufacturing, the product inspection results and equipment operating ratio information generated during manufacturing is now available as data that can be used from anywhere. Quality improvement, equipment malfunction prediction, and other initiatives that make use of that data are being carried out. In equipment malfunction prediction, for example, constant monitoring of the temperature and vibration of the equipment, and diagnostics based on a statistical model, are used to proactively prevent line stoppages caused by equipment malfunctions. Efficiently installing sensors and transferring the data to a network—essentially making production and other equipment IoT-ready, is essential to using the above technologies across a wide range of equipment. In the past, a huge amount of time was spent on tasks such as defining a data format and setting up a network. However, data formats and communication protocols are now being standardized internationally. Taking advantage of these standards is expected to enable the use of even more data.

Similarly, there are high expectations on advances in data use at the automobile design stage. Assessing designs and measures grounded in actual plant conditions is an important factor in automobile development and mass production. Knowing the dimensional accuracy of machined parts is crucial information in making a robust design. Similarly, information such as the operational status of machine tools is critical from the standpoint of line operation or the prevention of quality defects. Standalone measurements had been the norm, but advances in IoT technologies and their growing adoption have made ascertaining trends possible. The ability to use machine learning or other advanced predictive and decision-making technologies that require vast amounts of data has also led to more advanced quality control and operational management systems in plants. Using that data at the parts or equipment design stage is expected to enable evaluations and design that account for variation and other factors originating in plants or materials. At the same time, combining the data with VR and other technologies will provide improved and more extensive drawing quality at the design stage.

Carrying out the above initiatives has brought to the fore the issue of training and securing a digitally competent automobile manufacturing workforce that possesses both domain knowledge and digital skills. Relying only on teaching automobile manufacturing domain knowledge to digitally-skilled workers will not be sufficient to keep up with the growing use of digital technologies. How well automobile manufacturing engineers can acquire and use digital skills is therefore likely to become a major question.