PRODUCTION TECHNOLOGY AND PRODUCTION SYSTEMS

1 Introduction

In 2020, the rampant worldwide spread of COVID-19 turned everyday life upside down. The economic impact of lockdowns and other restrictions imposed in countries throughout the world is still being felt. This has also strongly affected automobile sales, with global figures for 2020 dropping below 80 million units. In Japan, combined sales of new registered vehicles and mini-vehicles in 2020 fell 7.6% compared to the previous year to 4,656,632 units, dropping below 5 million for the first time in five years.

Although the impact of COVID-19 on economic activity has continued into 2021, there is anticipation that the economy will recover and sales will increase as vaccination coverage rises. Under these circumstances, remote work is gradually taking hold in the manufacturing industry in Japan, and workstyles have reached a major turning point. Looking ahead, digital transformation (DX) is expected to accelerate and trigger further workstyle reforms.

At the same time, Japan has formulated fuel economy standards for 2030, and the electrification of powertrains is anticipated to gain momentum. However, there are challenges to address with respect to vehicle costs, the manufacturing of electric powertrains, and establishing a social infrastructure, making it difficult to predict the model life cycle of the various powertrains. Given expectations that the current full range of conventional to HV, EV (FCV) powertrains will have to be produced for the foreseeable future, it has become essential to adapt to flexible production. In addition, the transition to clean energy to achieve carbon neutrality and a carbon-free society in 2050 is intensifying the shift toward the electrification of vehicles and driving the reallocation of resources and introduction of new production technologies. That shift toward electrification is also predicted to lead to intensified competition as new corporations enter the automotive industry, and changes in workstyles, task processes and task allocation will have to be made at a faster pace than ever.

2 Vehicle Production Engineering (PE) Technologies

2. 1. Stamping

Social and market needs concerning automobiles have been changing substantially, and the post-2020 fuel economy standards stemming from environmental measures is accelerating development aimed at electrification. Electric vehicles (EVs) are equipped with batteries, which makes reducing the weight of the vehicle an essential element in extending their cruising range. However, responding to consumer needs for comfort and enhanced safety has resulted in constant increases in vehicle weight. Consequently, the contribution of weight reduction to improved fuel economy is rising year after year.

At the same time, producing highly attractive vehicles in a short time and at low cost has become critical to ensuring global competitiveness and contend with the inexpensive and rapid manufacturing of Chinese and other non-Japanese manufacturers

The field of stamping is subject to demand for technological advances that address weight reduction, high rigidity, and enhanced styling, and the further development of stamping technologies using high tensile strength steel sheets (ultra-high tensile strength material) and aluminum alloy materials for parts adapted to EVs is also expected to become necessary. Similarly, expanding the application of ultra-high tensile strength material and shortening lead times is crucial to stamping production technology with respect to building cars that meet customer needs, and further technological development will be required.

Efforts to shorten lead times are not limited to precise analysis simulations aimed at improving initial stage quality. They also include initiatives to reduce production preparation time by visualizing and quantifying surface quality. In addition, one approach to reducing weight involves replacing mild steel plates with ultra-high tensile strength material. Poor dimension accuracy caused by spring back is an issue in the press forming of ultra-high tensile strength materials. Predictive technology based on computer-aided engineering (CAE) and the study of countermeasures have recently expanded to material in the 980 MPa class or higher. Material and other related manufacturers are working on developing forming technologies for the 1.5 GPa or higher classes. Cost reduction considerations have been increasing the need for cold ultra-high tensile strength material forming technologies.

In contrast, the steel sheets constituting the majority of the vehicle frame consist of 590 MPa or lower material. Consequently, technologies that increase strength by streamlining part shapes, and also make full use of steel for inexpensive, general-purpose materials, are important in creating added value. Such technologies will have to be further enhanced to boost competitiveness.

2. 2. Welding

The environment surrounding the automotive industry has been undergoing tumultuous changes, with the shift toward electrification and the need to address future regulations (the green growth strategy for carbon neutrality, CAFE regulations) intensifying the need to reduce the weight and raise the rigidity of vehicles.

Multi-materials have been commercially introduced in European and luxury vehicles. Self-piercing riveting (SPR), friction stir welding (FSW) and laser welding are drawing attention as dissimilar material joining techniques that lead to greater ride comfort in addition to improving impact resistance, fatigue resistance, and vehicle rigidity. However, the attendant required facilities and technical constraints present a high barrier to expanding them to mass-production vehicles, prompting demand for diversification and advances in other welding and joining technologies as well.

In contrast, steel accounts for an overwhelming proportion of the vehicle body. The adoption of cold pressed 1.5 GPa class ultra-high tensile strength material and other efforts to effectively make full use of the steel illustrate that it is essential to improve welding technologies stabilize welding quality both in the standard case of welding ultra-high tensile strength sheets together, and also under more difficult conditions such as short pitches, high thickness ratios, or the joining of four sheets.

At the same time, thinner sheets are essential to reducing weight, but they have to be adapted to high damping mastic and other new materials that prevent a deterioration of outer panel quality, noise, vibration and harshness (NVH) performance, or feel, as well as used in conjunction with spot welding and the expansion of locations compatible with adhesive (Weldbond) that secures rigidity.

With respect to processes and production environments, a spotlight is being shown on life cycle assessment (LCA), which assesses energy consumption and CO_2 emissions through all stages from vehicle manufacturing, driving by the user, end-of-life, and recycling, as an important metric in evaluating manufacturing in addition to CO_2 emissions regulations. In response, initiatives relying on welding current calibration (controlling the welding current while monitoring the nugget) to achieve spatterless welding, reduce welding power, and appropriate power source use are being pursued to establish core technologies that reduce CO_2 during vehicle production.

At the same time, the application of the information provided by the digitalization of plants, and introduction of the Internet of things (IoT) is expanding to preventive maintenance and quality control (automatic inspection technology). There are high expectations for more efficient operations, workstyle reforms, and approaches to improving quality derived from the resulting big data, as well as AI.

In preparation for the future, establishing people-friendly processes for aging workers and women, as well as cooperation and collaboration with robots, is also an urgent task.

2. 3. Plastic Molding

Plastic molding is expected to meet the demand for reducing the weight of body parts, improving the texture of interior parts, decreasing CO_2 emissions, and eliminating dependence on petroleum. As electrification gains momentum, the issue of reducing the weight of vehicle bodies cannot be avoided, and all automakers are pursuing initiatives in that respect.

One such weight reduction initiative involves switching from steel to plastic for exterior parts, notably the back door. Various approaches, including

(a) the cost-focused pattern relying on inexpensive polypropylene (PP) and glass fiber reinforced PP,
(b) the hybrid pattern that combines steel and plastic, and

(c) the weight reduction-focused pattern that uses carbon fiber reinforced plastics (CFRP),

have been taken. There are also aluminum back doors in addition to those made of plastic, and the weight reduction of steel parts is anticipated to evolve in various directions in the future.

Foam molding represents a second approach to weight reduction. There are two types of foam molding: chemical foaming and physical foaming. In chemical foaming, a foaming agent is mixed into the plastic. This agent then releases gas during the molding process and very small pockets of space are formed within the material. In physical foaming, nitrogen and carbon dioxide gases are injected into the plastic while it is within the screw of the molding machine. These gases are then released into the plastic and very small pockets of space are formed within the material. In addition to weight reduction, physical foaming methods also possess superior dimensional stability characteristics. Until now, that technology was used frequently in interiors, especially door trims, and it has been receiving renewed attention as it finds its way into exterior parts.

Moving on to improvements in interior part texture, the switches that have always been on instrument panels, as well as soft instrument panel remain popular. In Japan, they are primarily used in high price range vehicles. Outside Japan, however, and notably in neighboring China, those technologies are also used in vehicles costing less than 2 million yen, and it is hoped that technology to apply then in low price range vehicles will be developed in Japan as well.

Spurred in part by interest in the SDGs, the topics of decreasing CO_2 emissions and eliminating dependence on petroleum are also drawing attention. The move away from gasoline vehicles and introduction of EVs is the prime example of those topics in the automotive industry. That applies just as much in other countries as it does in Japan. Electrification means cars will be equipped with large batteries to drive, and it will be necessary to consider what plastics can be used around those batteries. Battery covers are one example for large parts. In some EV battery covers, the bottom consists of a steel sheet, but the top is made of plastic (sheet molding compound: SMC). That example demonstrates looking into ways to reduce weight while taking the cover sealing, reduction of expansion differences with the steel sheet, and the required strength into account. Plastic production engineers will increasingly be required to consider, and propose, possible applications of plastic in parts used in EVs.

The plastic industry is actively pursuing efforts to use bioplastics and plant fibers to decrease CO_2 emissions and eliminate dependence on petroleum. The plant-derived polycarbonate (PC) plastic is frequently used in cars. Although plant-derived, it offers high transparency and is increasingly used for parts coated in metallic or piano black tones. While examples of plant fiber use is led by the adoption of parts molded by compounding kenaf or cedar fibers in plastic, cellulose nanofibers are a promising next step that is drawing attention as a technology affordable enough for use in mass-production vehicles. There is demand for the increased adoption of parts using such biological materials in plastic molding.

2. 4. Paint

Automotive paints provide styling and aesthetics through color, gloss, and texture, and play an important role in protecting the body from the use environment. Efforts to improve aesthetic elements such as smoothness and clarity are being complemented with initiatives to produce more stylish colors. At the same time, various measures are being applied to reduce the considerable amount of volatile organic compounds (VOC) and CO_2 emissions produced the painting process.

Initiatives to produce highly stylish colors include the expansion of two-tone colors, achieving high brightness or depth through pigments enabling the control of interference from colored clear coating or light, and the adoption of paints that use matte clear coating to suppress gloss. Although the conventional two-tone process that require multiple paint applications, alternatives such as applying a film or using an inkjet process that reduces the number of applications have been commercialized, contributing to energy saving and mitigating VOC emissions.

The adoption of high solid paints and waterborne paints has also been used to reduce those emissions. In facilities, technologies that decrease paint loss using highly efficient coating achieved through more effective electrostatic painting, and the further expansion of these technologies is anticipated.

Lower paint baking temperatures, more compact painting facilities, shorter processes, and the reuse of energy are examples of initiatives to decrease CO_2 emissions. Technology that eliminates the resin coating process through simultaneous bumper painting relying on low temperature baking has been commercialized. One example of making facilities more compact is placing the conveyor for the drying furnace outside the furnace, which results in heating only the vehicle body and saves energy. Painting booths are also reducing air conditioner energy consumption my making equipment smaller and optimizing its layout. To shorten processes, the number of paint booths is being decreased by reducing the number of times baking is performed during the painting operation, which involves multiple processes such as the application of the sealer and, undercoat, as well of the primer, base and clear coatings, and by integrating the various layers of paint films. Examples of energy reuse include recirculating exhaust air conditioned in the paint booth and reusing air conditioner energy. Exhaust air from wet booths is humidified and requires dehumidification and reheating, but that energy can be saved by switching to dry booths. Achieving the SDGs and carbon neutrality in 2050 will require going beyond environmental measures that simply extend current approaches. There are high expectations for the development of new paint hardening processes or other technological breakthroughs that will significantly decrease CO_2 emissions.

In response to the transformation brought about by connected, autonomous, shared & services, and electric (CASE) and mobility as a service (MaaS), the development of highly functional paints that provide surface treatments enabling the appropriate transmission and reflection of sensors, notably light detection and ranging (lidar), store electric charges, or acts as insulation to avoid the deterioration of the mounted battery life due to heat has begun.

It is hoped that industry-wide cooperation that crosses boundaries will intensify to advance such initiatives.

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 attaching harness wiring, plastic parts, or other soft parts.

Efforts to address diversifying customer needs, CASE, and carbon neutrality, have resulted various vehicle designs and categories, the addition of driver support systems or IT communication devices, and building of electric-powered vehicles, including HVs and EVs. This requires the mixed production of vehicles with considerably different structures, increasing the number of part types and widening the gap in work hours. Complex part selection and work procedures therefore require a high level of work quality, and worker burden is increasing.

At the same time, the low birth rate and aging of the population are intensifying the need to design processes and realize working environments that are friendlier to women and the elderly, and do not impose a heavy physical burden.

Solving those issues calls for building human-friendly processes by introducing assistive devices for the assembly of heavy parts, collaborative robots, or automatic conveyors, using ergonomic analysis create a better working environment by improving working height and posture, as well as preventing assembly errors and reducing the task burden by setting up a system that arranges the parts to assemble in advance and supplies them to the line (reducing worker burden by eliminating the need to walk, look for, and choose parts, and enabling workers to focus on assembly tasks). The above initiatives also lead to higher work quality, and are also applied to the building of processes that ensure stable quality with respect to the fluid labor force outside Japan.

Corporations from other industries have been entering the electric vehicle market, making it crucial to build competitive and attractive products in a timely manner. Initiatives applied to production processes include the standardization of facilities at the various production plants, and streamlining to build a flexible production framework, as well as taking advantage of IoT technologies to visualize facility operating conditions and quality information in real time, and making use of AI and collected big data to proactively prevent equipment failures or quality defects.

2. 6. Digital Technologies (CAD/CAM/CAE/xR/IoT/AI)

In vehicle development, reliance on computer-aided design (CAD), computer-aided manufacturing (CAM), and CAE contributes significantly to shortening the development lead time and improving quality. The relevance of 3D data is expanding as not only products, but production lines and entire plants are rendered in 3D to makes productivity assessments. Applying virtual reality (VR), augmented reality (AR) and mixed reality (MR) to that data enables assessments that are more grounded in reality, which helps decrease engineering changes and shorten development lead times. In addition, with the COVID-19 pandemic restricting the movement of people in and outside Japan in 2020, high hopes are being placed on MR as a means of working on tasks without traveling to the actual site.

Advances in digital technologies are also leading to the application of CAD data in various fields, keeping information linked from vehicle development until production. Consequently, the importance of managing CAD data and other information related to vehicle production has increased, resulting in more frequent application of product data management (PDM).

Automobile development has been said to symbolize development by consensus, and consensus building via telework or remote work is actively pursued to ensure the development of new vehicles does not come to a halt during the pandemic. Applying PDM to development and production information is essential to enable the parties involved to build a consensus in real time.

In addition, various production data elements are collected through the application of the IoT in plants, and analyses relying on AI technology are coming into use to improve quality in manufacturing processes. Interconnecting those data elements through PDM makes it possible to provide feedback on product design and is expected to lead to the rapid development of high quality products.

3 Powertrain Production Technologies

3. 1. Casting

The pandemic triggered by the novel coronavirus in 2020 shows no signs of abating, and continues to have a major impact on our day-to-day lives. The rampant spread of the disease and severe pressure on the health system turned everyday life upside down. Business trips and other travel was restricted to limit the spread of COVID-19, and there was a scramble to implement telework, web conferences, and other unfamiliar approaches. At the same time, the situation brought a fresh realization of how much had been entrusted to people or depended on them.

The history of casting is believed to have begun long ago with weapons and decorative articles, and while modern casting has mostly been mechanized, there is no denying that decisions based on human experience are still frequently relied upon at production sites. The linked management of manufacturing history and quality has become standard practice for quality assurance, but there are still only a few examples of making effective use of that collected data. The further development of casting will have to move away from manufacturing dependent on decisions based on human experience and require striving for efficient production that makes use of the IoT and of AI capable of analyzing the big data collected from improved sensing technology and making decisions in real time.

Another major change in 2020, partially fueled by rising environmental awareness, was stronger demand to achieve the SDGs and prevent global warming. The casting process consumes a large amount of energy, and simply extending existing energy saving activities will not be sufficient to realize carbon neutrality in 2050. The melting process, in particular, consumes a large amount of energy, and hopes are being placed on industry-wide consideration of way to reduce the number of times melting is applied before the product is finished, as well as on alloys that to not require a heat treatment.

The electrification of automobiles is moving forward at a frantic pace. A certain level of demand for cast products is anticipated despite the change in components brought about by electrification. However, weight reduction based on the use of lighter alloys or integrated molding that takes advantage of the characteristics of castings amenable to near net shape manufacturing will be necessary.

3. 2. Forging

The Japanese automotive industry is facing a major turning point following the announcements of not only more stringent fuel economy regulations, but also the government's declaration of achieving carbon neutrality by 2050 and its target of electrifying new vehicles in Japan by the mid-2030s.

The forging field is addressing expectations for further weight reduction to address fuel economy regulations and electrification through advances in hollow steel parts technology, a switch to aluminum alloys for chassis parts, and imparting high strength to reduce part thickness. Another technology under development to further reduce weight is the forging of magnesium alloys or other lightweight metals onto CFRP or similarly light materials.

Reducing costs calls for product-oriented efforts such as the optimization of part shapes through CAE and model-based development (MBD), integration through the consolidation of functions, and improving material yield, as well as process-oriented efforts such as reducing die costs, improving the utilization rate, and labor-saving measures. Similarly, production outside Japan is also expected to raise profitability through the local procurement of materials and dies.

While forging has high productivity, it also uses a considerable amount of heat that results in high CO_2 emissions. It is therefore important to reduce the energy used in machining by switching from hot to warm or cold forging, and find other ways to save energy not only in the forging process, but throughout all processes. Similarly, approaches such as switching from graphite lubricant to white lubricant, developing die materials and surface treatments enabling the use of lubricants with low environmental impact, and building environment- and people-friendly processes are being taken.

The rapidly evolving AI, IoT, and image inspection technologies are being applied to save labor by automating product inspections, prevent the outflow of defects by detecting poor quality products, and improve the utilization rate through preventive maintenance of equipment.

3. 3. Machining

In the field of machining, methods used to achieved the reduced friction loss that contributes to improved fuel efficiency include further smoothing the roughness of sliding surfaces, enhancing lubrication characteristics through texturing, and the surface reforming exemplified by diamond-like coating (DLC) are being constantly refined to raise efficiency by a few tenths of percentage points, and applied to various products.

In addition, high efficiency machining or consolidated processes that use general-purpose equipment are shortening production lead times and making production lines more compact.

To proactively prevent product or equipment defects, IoT is actively used to apply big data analysis technology to data such as part accuracy, machining load of the production equipment or electrical current values, improve product quality by providing feedback to the equipment, or for preventive maintenance.

Moreover manufacturers have started introducing automatic decision systems that merge deep learning with image processing technology for the final machined parts inspection process for machined parts previously entirely dependent on experienced engineers. The ambiguous decisions typified by scratches or burrs on the final machined product, were notably difficult to make as high susceptibility to ambient lighting conditions and poor camera sensitivity created a lot of visual noise, but improvements in AI technology are starting to solve those issues. Over time, automatic decision technology for parts inspection will become more commonplace as systems relying on transfer learning technology, which involves acquiring new knowledge by applying past experience, become capable of making decisions even with little learning data.

At the same time, it is necessary to consider the reduction of CO_2 emissions not just in vehicles, but also in the powertrain production process. Ongoing initiatives in that respect include adopting low energy consumption devices, reducing standby power, replacing the power sources in individual sectors with electricity, decreasing the quantity of equipment, and reducing the amount of coolant used during machining.

3. 4. Heat Treatment

Heat treatments are used to create a part with the required performance by applying an appropriate amount of heating and cooling to the metal. In automobile manufacturing, they are primarily used to improve the wear and fatigue resistance of powertrain components. The main heat treatment techniques include carburizing and quenching, induction hardening and quenching, and soft nitriding, and the choice of technique to apply is based on part shape, quality requirements, and cost. More recently, laser quenching and other technologies centered on more localized quenching and low distortion are being introduced.

The atmosphere gas carburizing furnaces, which enable large volume production and help reduce cost has been the mainstream furnace for the carburizing and quenching of powertrain parts, but it is gradually being replaced by the highly flexible vacuum carburizing furnace. Nowadays, it is necessary to produce a wide variety of powertrain types ranging from conventional engines and transmissions to units for EVs, and the resulting broad range of parts such as the various gears or pulleys for continuously variable transmissions (CVTs) is one of the reasons for the proliferation of parts with different shapes and performance requirements.

Vacuum carburizing furnaces are safe and secure as they reduce the risk of explosions because they do not use frame curtains or pilot burners. They also do not require seasoning when turned on and raise the temperature quickly, reducing both energy costs and CO_2 emissions. In one example, the high thermal insulation and low energy retention characteristics of the equipment itself have been reported to reduce CO_2 emissions by 50% compared to an atmosphere gas carburizing furnace. Other advantages include a high level of quality stability since there is no need to adjust the atmosphere during operations, and an improvement of about 10% in durability over an atmosphere gas carburizing furnace, without generating a grain boundary oxidation layer. However, the shape of the product must be considered before choosing vacuum carburizing as there are restrictions, such as the overquenching of sharp angles in the shape, on conditions and shapes.

In an attempt to reduce inventory between processes, it has the heat treatment process is being incorporated into the machining process, and the number of vacuum carburizing devices designed to handle a reduced number of lots is increasing.

The surface reforming often used in combination with a heat treatment is a mechanical treatment typified by shot peening. It is well known that shot peening applies compressive residual stress to the surface of a metal part by striking it with spherical shots measuring between 0.4 and 0.8 mm to improve compression fatigue strength. The emphasis on comfort resulting in making cabin space as large as possible, in conjunction with JNCAP test conditions that become stricter year after year, have been increasingly limiting the space available in engine compartment layouts and creating a demand for more compact powertrains. With the active adoption of techniques such as multi-peening steps, high hardness, fine particle, and warm shot peening, and even the WPC treatment that involves striking the surface of metal products at high speeds using fine particles mixed with compressed air, in addition to the standard impeller, shot peening is poised to become a savior for gear parts in such powertrains.

3. 5. Powertrain Assembly

Although trends such as the growing global momentum for electrification, the formulation of the green growth strategy in Japan are expected to encourage electrification in the powertrain field as well, a large number of current engines and transmissions are predicted to remain in production due to the many challenges faced by charging infrastructure and other issues. Those circumstances have made the establishment of flexible production lines that can respond quickly to changing needs a crucial issue for manufacturers.

In Japan, technology that automates existing processes and internalization are becoming major topics as the country struggles with the problem of labor shortage resulting from young people moving away from the manufacturing industry, the low birth rate, and the aging of the population.

Consequently, there is a need to combine high performance sensors, AI technology and image recognition technology to automate the subjective and visual inspection processes carried out by workers until now.

Another approach to automation to automation is the use of robots. However, it will be necessary to move beyond the current purpose of simple automation and consider making use of collaborative robots that will play roles such as compensating for the deterioration in muscular strength, vision, or other physical attributes of aging workers to reduce stress and enable veteran workers to exercise their skills.

With respect to quality, improving the level of process assurance by introducing interlock functions and inspection equipment has been steadily reducing the outflow of defects with physical causes. In contrast, there is still a gap between customer desires and in-house criteria concerning subjective defects such as vibration or abnormal noises. The current criteria-based quality assurance and pass/fail decision alone cannot bridging that gap and further raise customer satisfaction. Doing so will require intensifying efforts to build systems that leverage IoT technologies such as big data analysis, collect information and data on real world usage and feed the results of analyzing that data back into production lines.

As the demand for electrification continues to rise, it will be necessary to apply the knowledge and experienced gained from prior engine and transmission production to powertrains for HVs and EVs, build a production line serving as a base, and deploy it to bases outside Japan.