PRODUCTION TECHNOLOGY AND PRODUCTION SYSTEMS

1 Introduction

Despite the global automobile market recording sales of 90 million vehicles and the Japanese domestic market maintaining sales of 5.2 million vehicles, 2018 remained an unpredictable due to the intensifying trade dispute between the United States and China resulting from a rise in trade protectionism. Advances in automotive technologies are creating demand to address the CASE—connected, autonomous, shared, and electric—concept in addition to basic body frame weight reduction, material replacement, new fuel-saving technologies for engines, and the evolution of surface treatments. In the field of automobile production technologies, production lines tailored to electric vehicles (equipped with large batteries) and inspection technologies adapted to advanced driver assistance systems (ADAS) have become urgent needs. Furthermore, unsolved manufacturing quality assurance and management issues persist, and the effective application of artificial intelligence (AI) and of the Internet of Things (IoT) to production and quality data is raising expectations for advances in production processes and systems.

2 Vehicle Production Engineering (PE) Technologies

2. 1. Stamping

The automobile industry is said to be facing a once-in-a-century period of transformation that is intensifying the competition to survive. Even greater level technological advances are therefore required in the field of stamping, in which the most important issue is to provide customers with attractive products with higher added value at reasonable prices. In particular, electrification is making the development of advances in technologies that achieve highly rigid and light-weight vehicle bodies. Efforts by manufacturers to expand the application of high-tensile steel sheets (high-tensile materials) and aluminum alloys (aluminum materials) have led to developing ultra-high tensile strength steel plate in the 980 to 1,200 MPa class as a new advanced technology that provides excellent shape freezability and improves the durability of metal molds in downstream processes. In aluminum material machining, advances in technologies such as molding and mold surface treatments are minimizing the impact of metal chips generated after cutting on the final product. The application of these materials and techniques is being expanded to outer panel parts such as hoods and fenders.

Next, in the field of product evolution, highly stylish designs are increasingly used in exterior parts to enhance their appeal to customers, with stamping and molding technologies advancing correspondingly. With the short process, it is essential to make highly stylish, high-quality products that also have a reasonable price. Every manufacturer is undertaking efforts to reduce high materials costs in response to the percentage of the total cost represented by stamped parts. The development, purchasing, and production departments are cooperating with one another more than ever before to reduce costs in a multitude of ways, including using common molds for multiple parts, utilizing scrap materials, increasing yields, reducing the number of parts by applying ultra-high strength steel sheet, and integrating parts. After establishing such reliable technologies in Japan, intense efforts are made to spread them on a global scale to survive in various markets around the world.

2. 2. Welding

The most important requirements placed on automobiles, reducing CO_2 emissions, and improving fuel efficiency, vehicle safety, and handling performance, are increasing the need for lighter, more rigid vehicles. Replacing conventional materials with new ones is one way to reduce the vehicle weight, but this often greatly increases the difficulty of welding these new materials together. Manufacturers are therefore developing and commercializing new joining methods. Spot welding remains the most common joining method used for automobile bodies today, but the use of friction stir welding (FSW) and laser welding to join dissimilar materials has become more frequent. Common lightweight materials include high-tensile strength and aluminum materials, and over the last few years, hot stamping materials with a strength exceeding 1.5 GPa, which is higher than high-tensile strength steel, have increasingly been applied to automobiles.

In spot welding, the higher strength of the materials used has increased the difficulty of joining pieces together, and a high level of control is applied to the crucial welding conditions of electric current value, pressure, and energization time. The stronger the steel sheet, the more difficult it becomes to check the quality of a spot weld using a conventional chisel test, a situation that is prompting the growing adoption of non-destructive inspection equipment. The past difficulty associated with spot welding aluminum materials has been overcome through the use of high levels of pressure and electrical current, expanding the use of aluminum parts not only to covers, but also to roofs, doors, hoods, and even body frame parts. Numerous advancements in the development of bonding technologies, such as the use of adhesives, in addition to the use of fasteners have also been made for plastic materials as their application has expanded to more locations, and plastic body vehicles held relying on adhesive bonding are also commercially available. As electric vehicles become more common, further measures to reduce the weight and improve the rigidity of their body are anticipated to address the increase in weight resulting from the installation of large batteries. Automated, machine-centered welding plants are used not only for joining parts, but also for part picking and assembly operations. In addition, automatic monitoring of the operating status and quality and other visualization efforts are being made.

Examples of this include using IoT to predict equipment failures, as well as the inspection of all products and automatic feedback on its results, illustrating the broadening scope of the application of development facilities that use the latest sensing technologies. In contrast, although manual welding performed by skilled workers is still the norm in emerging nations, a transition to automation is underway to improve production efficiency and stabilize quality. In particular, instead of simply replacing workers with robots, reasonably priced technology is also put to use, and technologies that optimize cost and efficiency are being introduced. Technological development and applications, such as fastening bonding and adhesive bonding, are anticipated to accelerate in the future in response to the ever growing need to reduce weight. Furthermore, digitalization is expected to lead to the development and introduction of real-time detailed monitoring and response technologies for the plant operating status and information regarding quality.

2. 3. Plastic Molding

Plastic molding is used to reduce the weight of vehicle body parts for better fuel efficiency, to decrease CO_2 emissions by reducing the energy used in the manufacturing process, as well as to improve the quality and feel of interior parts. As autonomous driving becomes more widespread, technologies for bumpers will be required for vehicles equipped with advanced driver assistance systems (ADAS) and these technologies will play an important role not only in conventional product warranty, but also in guaranteeing functionality.

Weight reduction efforts have led to making bumpers thinner to reduce the amount of material used. At the same time, the development of new plastic materials in conjunction with the improvement of clear materials for painting and coating have resulted in bumpers that do not crack as easily and have a higher level of quality. Plastic materials has increasingly been used for lids, back doors, and tailgates, and shortening processes will be key to achieving both productivity and cost targets.

More and more hybrid injection molding machines are being adopted to reduce CO_2 emissions. The field of painting has been applying recycling that relies on air conditioning and replacing conventional materials with new ones to shorten drying times, but making the entire painting process is still a major issue.

Interior parts are expected to have both a high quality feel and appearance, especially in the context of improving the texture of the instrument panel. Illustrating the growing importance of developing production technologies that meet needs of customers, vacuum forming and advances in materials are sought to achieve a high quality feel at a low cost, while inexpensive stitching processes that can be used as appropriate in both mass-market and high end luxury models are one way to achieve high quality appearance.

Autonomous driving will require bumpers to provide permeability to the electromagnetic waves emitted from various sensors, which will necessitate managing changes arising from part thickness, paint film thickness, and paint color. As a result, there is an urgent need to develop a permeation measurement device to manage mass production and guarantee functionality. With globalization predicted to accelerate even more, expectations are being placed on advances in metal molds, plastic materials, and equipment technologies in Japan to answer the questions of how to leverage the advantages of plastic materials and production processes, and how well they are put to practical use.

2.4. Paint

As environmental awareness increases every year, automakers have been striving to further reduce emissions of volatile organic compounds (VOC) and CO_2 from the painting processes, which use a large proportion of the energy expended in automobile manufacturing. Water-based intermediate coat and base coat paints, as well as high-solid clear paints are increasingly used to reduce VOC emissions. At the same time, efforts to develop technologies that improve painting efficiency via better painting equipment are steadily bearing fruit. However, a rise in the number of intermediate drying facilities, higher CO_2 emissions from VOC combustion facilities, and other issues related to water-based paints are emerging. Advances in wet-on-wet painting technology, which applies an intermediate and top coating in one process and dries them simultaneously, have shortened the painting process and decreased the number of baking processes, along with wall-mounted robots allowing narrower painting booths and other measures, have resulted in significant energy saving and CO_2 reduction. These painting technologies must now urgently be deployed widely throughout the industry.

At the same time, there has been a remarkable diversification in the needs of paint products in recent years. In addition to the conventional needs, such as gloss and luster, to create a high-quality appearance, high saturation colors have become more common, and there growing demand, centered on mini- and light-duty vehicles, for decorative 2-tone and 3-tone paint schemes. However, additional painting to enhance appearance conflicts with advances in energy reduction technologies since it leads to repeating the painting process two or three times or increases the number of dedicated painting processes. The demand to reduce vehicle weight presents an additional complication. The established approach of lowering the specific gravity of sealers and undercoats has recently been supplemented with simultaneous coating technologies and high-viscosity foaming agents adapted to the use of multi-materials for weight reduction purposes to suppress vibration and provide even longer-term rust prevention. Further advances in the field of automotive painting are now sought to raise product value and respond to environmental concerns without sacrificing economic viability.

2.5. Vehicle Assembly

Vehicle assembly, the final process in vehicle production, is performed after painting is completed and involves assembling numerous parts together and carrying out quality assurance checks. Parts assembly is highly dependent on people due to the large variety of work procedures required by the mixed production of multiple vehicle models. Recently, expanding electrification and ever more diverse customer needs have resulted in more complex product specifications and an attendant increase in the number of parts on mixed production lines making multiple models. This is causing misgivings over the impact on assembly line workers, notably in terms of the burden of part selection work and assembly work. This is especially true for the manufacturing industry in Japan, where the declining birthrate and aging population is raising growing concerns over labor shortage and prompting calls to design and develop processes are not dependent on individual skill and expertise.

One example is switching away from the past approach of the worker selecting, and then assembling the parts. Instead, the need to search for and select parts is eliminated in favor of assembling parts that have been prepared and arranged in advance. This standardizes the work into a simple process that helps prevent the assembly of the wrong parts and shortens the distance walked while working. Promoting the creation of a more efficient work environment and construction of a more flexible production system plays an important role in vehicle assembly and is being implemented by making full use of automatic conveyance carts, collation and sorting devices, and various on-site improvements by individual workers.

At the same time, greater demand for safe and environmental friendly product requires more sophisticated manufacturing assurances adapted the new work and quality assurances designed to cope with advances in technology that go beyond electrification, such as autonomous vehicles and the connected cars brought about by the evolution of IT technologies. It is fully expected that the practical application of IoT and big data analysis technologies will make it possible to immediately ascertain the status of products, processes, and equipment, as well as ensure process assurance and optimize efficiency while maintaining stable production and providing the flexibility to deal with changes. Building a product manufacturing process that can cope with the evolution of technology, which encompasses "a work environment allowing exclusive focus on assembly work" and "assembly technologies that prevent workers (people) from making mistakes", now fall within the scope vehicle assembly.

2. 6. Vehicle Inspections (VQ)

A major role of the vehicle inspection process is to guarantee that the inspected completed vehicle is in compliance with the laws and regulations of the countries to which it is shipped. The process must also guarantee the uniformity of a single completed vehicle adapted to a customer's requirements and ship it to them. In light of both the current state and upcoming evolution of vehicle equipment specifications, government agencies in various countries have started discussions with the automotive industry to organize and establish requirements for appropriate legislation concerning forms of quality assurance unlike that of conventional vehicle equipment and functions that will be required by driving support systems, and connected vehicles.

One initiative to guarantee the functionality of driving support systems requires establishing a mechanism to certify the traceability of data, including the manufacturing history and manufacturing records for each process, and the completed vehicle inspection results. Software that can centrally manage the numerical data from those inspection results and analyze trends has been introduced in some plant inspection lines, making it possible to accumulate functionality assurance data. Monitoring these data trends also expands the use of this information to preventing the outflow of defective parts and implementing preventive maintenance at completed vehicle inspection facilities.

In addition, revised laws and regulations concerning completed vehicle inspections went into effect in June 2019, making it necessary to replace the current inspection equipment and sensory inspection by inspectors with controls tied into the system. Until now, determining whether an inspection item receives a passing grade has mainly relied on human senses (sight, hearing, touch, and smell), and quantifying these inspection results in a manner consistent with productivity is technically very difficult, making evolution of a general-purpose technology is a necessity. The addition and application of the latest AI technology in a supplementary role is expected to further advance the construction of a vehicle inspection environment that will reduce the burden on human inspectors and enhance traceability.

2. 7. CAD, CAM, and CAE Systems

Computer-aided design and computer-aided manufacturing (CAD and CAM) digitization technologies are evolving and seeing more widespread application in various fields, with notable advances in the use of knowledge data from computer-aided engineering (CAE) simulation technology. Using accumulated past data, the outer panel design surface can now be examined when the product is designed to ensure it is optimally shaped to align it the shape of the inner panel. It has also become possible to quickly examine simulations of outer panel molding. The CAE and CAM linking accuracy is also being improved by dramatically shortening the examination time and utilizing mold data.

In addition, when setting the welding points for the spot welding robots used in welding plants, CAE is used to conduct a preliminary study via desktop simulation to match the welding processes and the order of the welding points to the model. The lead time for the final adjustment with the actual equipment is then shortened by setting the optimal teaching data for robot operation and welding point distribution. Personal computers and tablets were introduced to ensure the quality of the assembly process procedures learning assistance process, as well as the logistics and distribution management at assembly sites. This is expected to be effective at guaranteeing the quality of manual assembly and tightening work, shortening the time needed to achieve proficiency, and improving work efficiency. A modified form of preventive maintenance involving collecting and monitoring the operating status data of the production equipment is beginning to be applied to assembly line management and maintenance on some lines at production plants.

Recent advances in IoT technology have made it possible to clearly visualize the manufacturing and production data of the whole factory, including the planned number of production lines and their actual status. Other initiatives link product design values to manufacturing conditions in the manufacturing process, part quality, and inspection characteristics data to ensure traceability of manufacturing quality, provide solution analysis to improve the quality of the manufacturing process, and reflect any feedback back into the original product design. Moving forward, further improvements in IoT and AI technologies are expected to improve the overall manufacturing process, increase efficiency, and improve quality.

3 Powertrain Production Technologies

3. 1. Casting

The field of casting technology is responding to the evolving automotive technology trends of weight reduction and lower fuel consumption by making parts lighter and thinner than before. This requires high-level control of manufacturing processes to meet the requirements for complex shapes, highly accurate dimensions, and special surface properties of parts such as cylinder heads. Electrification will reduce the currently high number of cast parts in use, and an increase in materials with new functional requirements needed by electric power units is predicted.

With global exhaust emission regulations slated to become even stricter by the year 2030, a target value of over 30% has been set for the percentage of electric vehicles. Consequently, the percentage of all vehicles represented by vehicles with gasoline engines amongst all vehicles expected to peak in 2030 and start declining thereafter. Electrification is also expected to lead to a decrease in the production of gasoline engines, resulting in a corresponding decrease in the casting materials required in vehicles.

These changes in the automotive industry will make it necessary to expand the application of high-vacuum technology to the aluminum die casting (DC) manufacturing process to allow thinner walls, higher quality, and higher strength in aluminum materials and address the changing functional requirements for future materials. In addition, inorganic sand core binders that suppress gas generation is increasingly applied in low pressure die casting (LPDC) to cope with the increasing complexity and quality of cylinder heads. The growing demand for higher quality and functionality is further expected to prompt advances in, and expand the use of, in-line quality inspections and quality assurance technologies.

The change in the number of parts due to electrification presents a challenge in terms of improving the production efficiency of existing systems and underscores the importance of technology for stabilizing part quality and the operation rate. One example is constructing a stable production system that does not rely on manual labor by expanding the application of technologies and automation technologies that improve mold life, such as mold temperature control technology, release agent technology, and mold surface treatment technology. Expectations are rising for technological advances such as the construction of a casting system that can produce high quality parts stably and efficiently using IoT and AI technologies that already being commercialized.

3. 2. Forging

A look at the forging industry in 2018 reveals that 70% to 80% of hot forged parts are for automobiles, the majority consist of engine parts such as crankshafts and connecting rods, transmission parts, or suspension parts. The Japanese manufacturing industry as a whole is undergoing a major transformation. For the ten years until 2030, the year representing a major turning point for electrification, the proportion of internal combustion engine vehicles will remain dominant and the rise in demand for conventional parts will intensify the need to further reduce costs and to guarantee sufficient supply. As a result, it will be necessary to reduce non-operating loss, improve material yield, decrease mold costs, and build a stable production framework, as well as to improve profitability through local procurement of raw materials and molds for parts produced outside Japan.

Furthermore, thanks to electrification the next-generation of engines and transmissions ten years from now promises to be more compact and offer higher added value due to smaller and lighter components as well as the integration of multiple functions. New production methods that integrate multiple parts and reduce weight to improve the overall fuel efficiency of the vehicle will therefore become predominant. Servo presses for forging are leading to advances in conventional net shapes and are being introduced as an innovative method to shorten the process. The development of superior construction methods that support multi-product variable volume production in the future is desirable, and it is also necessary to complement higher production efficiency with the creation of worker-friendly processes, standardization through digital management, and other active uses of

IoT. It will be necessary to reform the forging production process and strengthen its competitiveness to make it viable on a global scale.

3. 3. Machining

Automakers are stepping up their electrification efforts in response to stricter regulations aimed at reducing CO_2 emissions. However, the switch to the production frameworks adapted to the rapid rise of electrification presents lingering challenges, such as installing infrastructure, in many countries around the world. For the time being, manufacturers will therefore have to navigate this period of transformation while developing and supplying new powertrains that contain electric motors and take advantage of long established Japanese hybrid technologies. Parts machining is required to result in engines with greater thermal efficiency and transmission with less drive loss, which means that the machining technologies must shorten development lead time with a flexible production system, improve the accuracy of the machined surfaces to improve performance, reduce the weight of materials, and process complex shapes.

Realizing products with a high degree of functionality and the required precision at a low cost is a challenge that makes the development of manufacturing methods coordinated with the materials, processing, and assembly departments essential in product development. Until now flexible production systems for machining have involved a line configuration with machining centers arranged in cells, and introducing high-speed and high-feed machining technology for tools. However, maintaining the quality of each cell at the same level presented issues such as an increase in the number of work hours needed for monitoring.

New advances in robots and measuring technologies are being applied to the automation of inspection and measurement tasks, parts conveyance, and tasks performed between processes. In addition, increased image processing resolution, and the implementation of automatic inspection of surface defects and in-line inspection of grinding surface defects, combined with a traceability system, have raised the level of quality assurance.

Initiatives relying on AI for equipment status and line management add data collection devices to existing equipment to ascertain the operation status in a timely manner and proactively prevent potential issues leading to quality degradation. Differences in equipment-related work hours resulting from multi-model production will require evolving such initiatives into a system that comprehensively manages everything from production to maintenance planning, allowing both equipment and people to work at maximum efficiency, and also include deliberately setting up automatic planned maintenance.

3. 4. Heat Treatment

Heat treatment processes include intermediate treatments to improve formability, and treatments that enhance functionality. This section covers technical trends for the latter, which are the main type of treatment. As stated previously, vehicle weight is being reduced to decrease fuel consumption. Although the steel materials for various automobile parts are being replaced with aluminum and plastics, parts made from heat-treated steel are still indispensable, mainly in the drive system, due to their excellent balance of high strength, high reliability, and low cost. This is expected to remain the case for the foreseeable future.

However, growing demand for environmentally friendly vehicles grows and the expansion of electrification are likely to impose even more stringent requirements in the areas of new parts, downsizing, weight reduction, complex shapes, and higher strength, and the development of strain control technologies, in combination with high-concentration carburizing and carbonitriding, is predicted to become more important.

In gears for the transmission, for example, carburizing treatments remain the mainstream approach due to the superior wear resistance they achieve, but manufactures have started switching from gas carburizing to vacuum carburizing to reduce CO_2 emissions and raise thermal efficiency.

However, despite the considerable effectiveness of vacuum carburizing at reducing plant CO_2 emissions, it falls below expectations in terms of reducing total energy consumption. Further improvements in equipment and carburizing technologies are anticipated as the application of vacuum carburizing increases.

Compact, cell-based vacuum carburizing furnaces have been attracting attention as the next step in the evolution of vacuum carburizing technology due to the need to reduce intermediate fluid inventory and production lead times. This is expected to lead to the development of an in-line and simultaneous production flow by skillfully conducting comprehensive process design that includes the machining processes. Similarly, introducing induction hardening into the production method is also being studied as a means of in-line simultaneous production, and is expected to expand to the production of some transmission gear parts. Large gears and other parts that do not have particularly strict requirements for gear tooth surface strength, for example, should be able to capitalize on the advantages of induction hardening. There are also some localized quenching technologies that use lasers or electron beams. They are currently limited just to a few automotive parts due to cost and hardening range limitations, but offer energy-saving benefits by supplying only the necessary energy to the necessary locations, and are therefore expected to see wider use in the future.

3.5. Powertrain Assembly (Including Electric-powered PU)

Powertrain assembly lines also face the challenge of establishing production lines that can quickly respond to a wide variety of consumer needs and sudden changes in society. With power units for electric vehicles, in particular, standardizing lines and determining the applicable technologies to switch to the optimal line in a timely manner is becoming a necessity. In terms of quality, initiatives are focused on standardization to achieve the same level of quality on a global scale and on ensuring quality assurance through integrated development and production. Initiatives have already been initiated in regions that have introduced hardware to make use of big data, and differences in the infrastructure to support automation is presenting challenges with respect to the need for data acquisition and the establishment of effective use of data.

Even as efforts to improve their productivity and quality by promoting digitalization are underway, strengthening the production structure and establishing advances that capitalize on regional characteristics through actions such as incorporating ideas unique to the region based on the basic design of the assembly process are also acquiring greater importance. It is also thought that automobile part standardization and applications not bound by existing frameworks will play a more important role in the development of technology that will improve competitiveness on a global scale.

Power unit assembly for electric-powered vehicles is focusing on enhancing the quality and stability of the motor assembly process. In the stator assembly process, the automated equipment for wire processing, assembly, painting, impregnation, and heat treatment, as well as processes performed manually such as inspections, are optimally arranged to maintain a high level of line flow efficiency. The rotor assembly process requires high quality and high productivity for the magnet core assembly and magnetizing process, making both part and assembly quality crucial.

Increases in the number of models subject to electrification and in production volume will require measures for different product specifications and sizes, and the issues of examining vehicle specifications in consideration of global production and of the evolution of production lines will have to be tackled.

References

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