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Key Manufacturing Technology & Equipment for Energy Saving and Emissions Reduction in Mechanical Equipment Industry

Zhongde Shan[1,#], Shaoyan Qin[1], Qian Liu[1], and Feng Liu[1]
1 State Key Lab. of Advanced Forming Technology & Equipment, Advanced Manufacturing Technology Center, China Academy of Machinery Science & Technology, Beijing 100083, China
Corresponding Author / E-mail: shanzd@cam.com.cn, TEL: +86-10-8241-5109 / 8241-6121, FAX: +86-10-8241-5078

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Based on analysis of the current situation in the mechanical equipment industry, this paper introduces manufacturing technologies and equipment for sustainable development in the mechanical equipment industry. This paper will consider 8 aspects: digital technology, new material, near-net shape forming technology, clean production, short production process technology, waste-free manufacturing technology, automatic control technology, and remanufacturing and reusing technology. It is also important to consider, that as a powerful manufacturing country, we should develop technology and equipment in such a way that protects resources and promotes sustained environmental development. This way, we are able to provide technical support while building a resource-conserving and environment-friendly society.

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1. Introduction

The mechanical equipment industry has a direct impact on achieving the goals of energy saving and emission reduction in all trades and professions, such as electric power, metallurgy, petrochemical, and other industries. However, there are many problems in the mechanical industry, such as high energy consumption, low manufacturing accuracy, high machining allowance, high waste rate, low production efficiency, high waste emissions, etc. Most of the energy consumption and pollution are generated in thermal processes such as casting, forging, and heat treatment, where the energy consumption and the pollutants account for 60~80% in mechanical industry. This is exemplified by the fact that, about every year, 100 million tons of metal materials worth about $250 billion are cut off in machining process.[1-3]

Therefore, it is imperative to research and expand the use of green manufacturing technology to save energy and reduce emissions. Doing so will provide technology and equipment support for the manufacturing industry, at the same time allowing for sustainable development. Reducing influence on the environment and resource consumption in the manufacturing process will make it possible to balance both the enterprise's economic and social benefits.[4-7]

2. Technology & Equipment for Sustainable Development in the Mechanical Equipment Industry

In the machinery industry, energy saving and emission reducing manufacturing technologies consist of three types: resource conservation, energy economizing and environment-friendly. These mainly refer to simplifying the components of process system; saving the consumption of raw and auxiliary materials; reducing energy consumption; and minimizing or completely eliminating generated waste water, waste gas, waste residue, noise and other substances which affect or harm the environment and the operator during the process of designing, manufacturing, using and remanufacturing.[8]

In recent years, with the fast development of electromechanical integration technology, computer technology, information technology, control technology, etc., all the excellent achievements of these technologies are continuously absorbed to improve the development of manufacturing technology. The trends of digitization, precision, flexibility, intellectualization and greening are a part of that process. Many design, manufacture and control technologies have been emerging and these have been gradually applied to the manufacturing equipment industry. Some examples are digital technology, new material, near-net shape forming technology, clean production technology, short production process technology, waste-free manufacturing technology, remanufacturing and reusing technology, and automatic control technology. These effectively promote sustainable development in the industrial field.[9-15]

2.1 Digital Technology in the Equipment Design and Manufacturing Process

With the rapid development of IT industry, digital design and manufacturing have become an important approach to improve the equipment manufacturing industry and enhance the core competitiveness of enterprises. The digitization of designing, which includes material selection and product design, has improved the manufacturing and management process. Product development and manufacturing have also improved, the number and weight of parts has been reduced. By optimizing the design method, the usage rate of raw materials can reach the highest level. All of the above measurements effectively promote energy conservation and emission reduction during production. In Boeing Co., through the modern product development system, the new product development cycle has been reduced from 8 years to 5 years; the engineering rework rate has been reduced by 50%. Toyota Motor in Japan has reduced the development cycle by 10 months. During the R&D period of the new Kamei car in 2002, the prototype testing period was reduced by 65%. In the foundry industry, the traditional pouring gate, riser and their design principles are improved by visual casting technology, which has optimized the pouring process and the sizes of the pouring system and the riser system.[16-18]

Virtual reality can be integrated with multiple analog simulation technologies. In the early stage of equipment design, the simulations for the whole process, which include product design, process design, processing production, using and recycling, and so on, are rendered by modeling and simulation technology. This includes multiple physical fields numerical modeling, processing and forming process simulation, high speed and high precision processing equipment simulation, digital collaborative product development, etc. At the same time, the environmental factors and measures of preventing pollution are taken into account. The relevant design factors are optimized, reducing the overall impact on the environment from the product and its manufacturing process. For example, by applying the virtual reality technique, the CAMTC, through the design and evaluation of their ultra-high strength steel production line, has shortened their design cycle by 20~40%. Doing so makes it possible to foresee many manufacturing problems, as shown in Figure 1.[19,20]

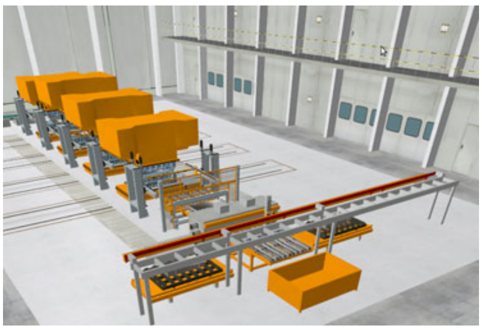


Fig. 1 Design and evaluation of production line

2.2 The Development and Application of New Materials to Reduce the Weight of Mechanical Equipment

Innovative technologies promote the development of new high-tech materials, which are characterized by higher strength, stiffness, temperature resistance, corrosion resistance and wear resistance. The research and use of new materials such as composite materials, light metals, and high temperature alloys, which were previously used in space and military applications, has been extended to civilian value-added industries (automobile, computer, communication, electrical appliances, etc.), especially for the automobile industry.

By using new materials in the structure, the performance of new generation of airplanes and aircraft engines could be improved by 50~70%, and the weight of airplanes and aircraft engines could be reduced by 70~80%. Take a car as an example: if the weight is reduced by 10%, the fuel economy will improve by 6~8%. CO2 emissions will also be reduced, which has a great influence on energy savings and environment protection. The weight can depend on the use of new materials in the automobile. Over 60 kinds of components on the automobile could be made of magnesium alloy, such as clutch housing, transmission housing, steering wheel, seat bracket and instrument tray framework. By developing and applying ultra-high strength steel, the CAMTC has lightened the weight of the door beam by 30~50% with stronger anti-collision capability, as shown in Figure 2.[21,22]

2.3 Clean and Efficient Part Manufacturing

With more and more attention being given to resource and environmental protection, the manufacturing process is moving towards precise forming. This means that the accuracy of the shape and size of the blank is changed from extensive forming to the near net shape forming or even net shape forming. The clearance between the blank and parts may be smaller and smaller, with some

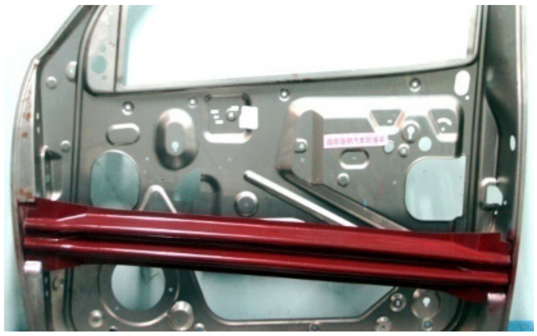
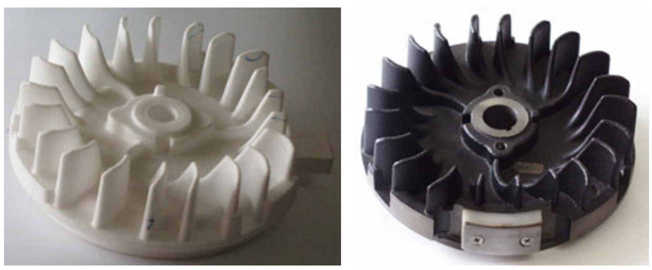


Fig. 2 Ultra-high strength steel lightweight door beam



(a) Lost pattern (b) Casting part

Fig. 3 Casting flywheel by lost foam process blanks near to or reaching the final shapes and sizes. These could then be assembled after being grounded. For example, the United States has put forward the following goals: consumption of raw materials reduced by 15%, processing of waste fragments reduced by 90%, energy consumption reduced by 75%, and the lifetime of forged forming dies improved by 10 times in 2020. The gray iron cast flywheel, as shown in Figure 3, reduces the weight by 10~15% when manufactured by lost form casting process.[23,24]

Hollow parts with a section of round, rectangular or abnormal shape which changes along the axis can be shaped with internal high-pressure forming technology. Compared with turning and boring components, the hydro forming hollow shafts can be reduced by 40~50%, even up to 75% by weight. Compared with stamping and welding components, hollow structural parts can be reduced by 20~30% by weight. To take the radiator bracket as an example, the number of welding points is reduced from 174 to 20, the number of manufacturing passes from 13 to 6 passes, and the production efficiency is increased by 66%. Compared with mechanically processing components, internal high-pressure form manufacturing of a hollow crankshaft with two turns saves 87% of the materials and reduces the weight by 57% compared with the solid shaft with the same torque.[25,26]

2.4 Promote Clean Production in the Manufacturing Process

Clean production in the manufacturing process of equipment parts mainly includes clean machining such as dry cutting and laser deburring, clean coating or plating, clean heat treatment, and so on. However, there are many drawbacks in the traditional processing method. For example, the slathered cutting fluids in traditional processing can not only cause the environmental pollution, one of the most serious pollution sources for soils and rivers, but also cause micro-cracks on tool surfaces, which can shorten tool life. As a result, new, clean production methods such as dry cutting and near dry cutting, are attracting more and more attention. During dry cutting, the cutting point is generally cooled with a strong air current or other cooling medium, bringing the generated heat out, thus the thermal deformation of the work piece is very small. At present, dry grinding has been adopted broadly in the manufacturing industry of U.S., and dry cutting technology has been adopted by half of the European enterprises.[27,28]

Vacuum coating has been gradually replacing electroplating in automobile wheel hub coating, and the recycling technology known as “organic solvent” is being adopted in equipment painting. Vacuum coating equipment and technology have also been applied to other types of equipment, including the intermediate frequency magnetron ion plating machine, the multi-arc ion plating machine, and the magnetron plus multi-arc ion plating machine. For example, Douglas Company of America has used the drumtype ion plating equipment to process connection parts. And in Japan, carbon steel bolts made with ionized aluminum plating have been put into production instead of stainless steel. However, traditional electroplating industries have not been widely upgraded with these advanced coating technologies.[29]

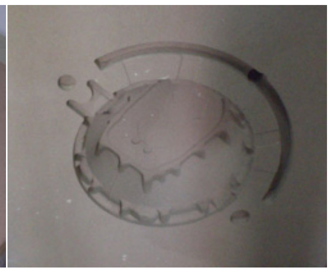
Furthermore, continuous generation of thermal radiation, waste gases, waste water, dusts and noise during heat treatment cause a certain degree of pollution to the environment. High efficiency, energy savings, low distortion, and clean processing are the important development directions of heat treatment technology. With the rapid development of modern automobile manufacturing, the demand for high-performance forgings is increasing. Automotive manufacturers are paying more and more attention to micro-alloy non-quenched-tempered steels because they allow for lower consumption of energy and materials, reduced pollution and a shortened production cycle.[30]

2.5 Short Production Process to Reduce Resource Consumption

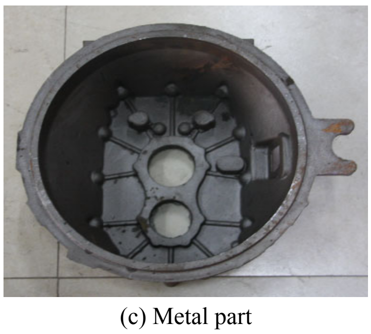
Short production process makes full use of materials and heat in the pre-production process, or integrates several processes to reengineer the entire manufacturing process. For example, the high quality complex castings are directly manufactured with the molten iron smelted from blast furnace. In recent years, the research of short process smelting technology with the blast furnace-medium frequency induction furnace has been carried out at home and abroad. This way, hot metal from blast furnace can be shifted directly to a medium frequency induction furnace to adjust the temperature and composition, which produces a high-quality casting of molten iron. Compared with the conventional melting process, it eliminates the process of cooling molten iron from the blast furnace and cast iron re-melting, and takes full advantage of the heat of molten iron from blast furnace. The equipment has high energy efficiency while reducing energy consumption and emissions.[31]

Although the low pressure casting technology has been widely adopted in producing the aluminum alloy wheels for the auto industry, the forging-spinning composite forming technology has been developed to meet the demand of this application. Lightweight (the weight of forged aluminum alloy wheel is 23% lighter than by

(a) Lower sand mould



(b) Upper sand mould



(c) Metal part

Fig. 4 Sand mould without pattern of automobile parts casting) and high-performance (the strength of a forged aluminum wheel is 5 times greater than that of a steel wheel) parts are necessary for large passenger cars, heavy trucks and luxury cars. In the stamping process of ultra-high strength steel, steel plates would be quenched and cooled by the mold directly. The forming and quenching processes would be united into the same process within the same mold simultaneously, which can reduce working procedure and shorten the process.[32,33]

Many types of new manufacturing processes, which are distinguished by their fast, efficient and clean manufacturing equipment, are widely applied in many areas and also used in the machinery and equipment industry itself. For example, sand CNC machining, a processing technology that does not use molds or patterns, has largely shortened the production process. It is based on the multi-disciplinary technical achievements of numerical control, casting, computer and others. Compared with traditional technology, the processing costs would be only about 1/10 of that, the development time reduced by 50%-80%, and manufacturing costs would be reduced by 30%-50%. The casting mold produced by CAMTC could provide customers with one to twenty parts castings in three weeks rather than 2-3 months using traditional technology. According to the sizes and complexities of different castings, their dimensions can be up to 5 m. As shown in Figure 5, the casting size of automobile shell produced by the technology of casting without mold is 560mm×370mm×185mm. It only cost 25 hours to process the sand mold, with the machining allowance reduced by 3mm. This will save molds, including inserts, by 3~5 sets.[34,35]

2.6 Waste-free Manufacturing to Promote Resource Recycling

A new generation of manufacturing technology called "Waste-free Processing", proposed by the United States, either generates no waste in the processes, or makes use of the waste as raw stuff in the other processes. Waste-free manufacturing can not only reduce waste, pollution and energy consumption, but also protect the environment, which will inevitably become the main stream of advanced manufacturing technology in the future. A new concept of environmental protection known as "3R", namely Reducing waste, Reusing and Recycling, has been proposed by Japan. Since the 1980s, in Japan 86% of foundries have adopted sand reclamation while per ton of waste casting sand would bring about 0.22 tons of emissions and consume only 0.135 tons of new sand. In the U.S. some foundries have achieved "Waste-free Producing", or rather production without discharge. The recycling and reusing technology along with the waste-free target is an important approach to realizing the goals of energy saving and emission reduction. This is especially important in heavily polluting industries such as casting, cement, thermal power, printing and dyeing.[36]

Fig. 5 Digital precision forming machine without pattern casting

2.7 Automatic Control to Improve the Efficiency of Equipment

Automation in the manufacturing process is an important aspect of energy saving and emissions reduction in machinery and equipment production. Energy economizing and environmental protection can be achieved by using integrated innovation and system optimization, researching large-scale high reliability automatic sets of control systems and network systems, developing the technology of flow simulation of complex processes, using large-scale software for optimization, using an energy network monitoring and control system and implementing integrated automation of industry processes.

In forging industry, the "Auto forging cell" could complete the forging process of upsetting, preforging, finish forging, punching, trimming, shaping and so on in a single device which could finish one product for every 2 seconds with high efficiency and ensure temperature and technique stability in the forging process. In the casing industry, a digital precision forming machine without pattern casting, as shown in Figure 6, developed by CAM, could reduce the time of machining a sand mold and core by applying auto-control technology, which could immensely improve the production efficiency of processing single or small batch casting.[37,38]

2.8 Promotion and Application of Machinery Equipment's Remanufacturing and Reusing

As a green manufacturing technology, the remanufacturing technology is guided by the theory of product life cycle. The aim is to enhance the performance of the waste or old products, with high quality, high efficiency, energy saving, materials saving, and environmental protection as the principles, combining this with advanced technologies to achieve the goal of resources' reuse and reproduction. Re-manufacturing has an important feature: the products' quality and performance can meet or exceed new products' after remanufacturing, and the cost can be only 50%, with 60% energy saving, 70% material saving and lower adverse effects on the environment. Nano-brush plating, nano-thermal spraying, laser cladding, and self-repairing nano-additives, etc. have become the key supportive remanufacturing technologies. For example, Caterpillar Corporation has over 30 years' experience of remanufacturing and has the capability of remanufacturing more than 2 million old products in a year. Remanufactured products provide the same quality and warranty claims as new products, yet at half of the new products' price. In the foundry industry, there are also ways to remanufacture and reuse. Repairing large casting scraps to improve the yield and avoiding secondary scrap melting have proven to be an effective method.[39,40]

3. Conclusions

With the development of electronics, information, materials and modern management technologies, developing advanced manufacturing technologies makes it possible for us to build a resource-saving, environmental friendly society. Achieving the sustainable development of the machinery equipment industry is one of the main tasks in the future of equipment manufacturing.

It is important to promote sustainable development in the equipment manufacturing industry in order to develop and promote energy saving and emission reduction technologies. This can be achieved during the processes of designing, manufacturing, using and remanufacturing, using such things as digital technology, new material, near-net shape forming technology, clean production technology, short production process technology, waste-free manufacturing technology, automatic control technology, and remanufacturing and reusing technology. The goals of energy saving and emission reduction can be achieved with the research and application of these new green technologies and equipment. By reducing raw materials consumption, energy consumption and environmental pollution, this will promote sustainable development in the mechanical equipment industry.

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