A Modular Production System That Can Respond to Changes in the Market

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In recent years, the functional chemicals industry has been facing various changes in the market, such as diversifying customer needs, shorter product lifecycles, rapidly growing markets in developing countries, and the need to reduce CO₂ emissions and waste. A promising solution is a modular production system, which modularizes the operation units of the conventional batch production and can easily reconfigure them. This paper outlines the features of this system and the trend of international standardization of the module type package for automation engineering. It also explains the iFactory project, which is leading the implementation of modular production systems in Japan, and Yokogawa’s efforts in this project.

INTRODUCTION

In recent years, many demonstration tests have been carried out in order to introduce modular production systems to the manufacturing of functional chemicals, such as synthetic pharmaceuticals and plastics, and there is a growing trend of international standardization of such systems. One reason is that there is a need to keep up with market changes by responding to various issues such as high-mix low-volume production, improving the efficiency of manufacturing processes, decarbonization, and reducing waste. The modular production system using the continuous flow method is expected to solve these multiple issues simultaneously. In this system, the operating units of the batch production system are modularized and can be freely combined and configured. To implement this system, standardized rules that allow the modules to be connected freely are needed.

This paper outlines the characteristics of the modular production system and the international standardization activities of the Module Type Package (MTP) for automation engineering of the system. It also introduces the iFactory project, which is leading the implementation of the system in Japan, and Yokogawa’s efforts in this project.

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CURRENT STATUS OF THE CHEMICAL INDUSTRY

Supply Chain in the Chemical Industry

The supply chain of the chemical industry can be divided into three areas: upstream, midstream, and downstream. The upstream area produces ethylene and other basic chemicals from fossil resources. The midstream area chemically processes basic chemicals to produce intermediate chemicals such as pharmaceutical intermediates, organic chemicals, and functional materials (synthetic resins). The downstream area processes the intermediate chemicals to produce final chemicals, such as materials used in parts of automobiles and electrical appliances.

To produce basic chemicals in the upstream area, continuous production is used for mass production with high energy efficiency. Meanwhile, batch production is used to produce functional chemicals in the midstream area for high-mix low-volume production. This is because the batch system used during R&D tends to survive in product manufacturing, and because it is impractical to build plant facilities for each individual product for high-mix low-volume production required for various applications in the downstream area⁴⁰.

Shifting to the Modular Production System

The manufacture of functional materials involves various issues such as the need to improve production efficiency and product quality in batch production systems, the decrease in the working population, and environmental measures when disposing of by-products. Meanwhile, emerging issues in recent years include diversifying customer needs, short product lifecycles, rapid expansion of the market in developing countries, and reduction of CO₂ and waste. Although high-mix low-volume production is needed to meet diversifying customer needs, it is impractical to build plant facilities for each product. Therefore, it is necessary to configure existing production systems flexibly, streamline the engineering work, and start up a new production line quickly. It is also necessary to reduce energy consumption because the chemical industry is the second largest emitter of CO₂ among manufacturing industries after the iron and steel industry. Large amounts of energy are consumed for heating and cooling in batch processes, and additional energy is consumed in the disposal and detoxification of by-products generated during manufacturing.

To solve these problems, the modular production system is attracting attention and is actively being introduced worldwide. This production system automates and modularizes unit processes of batch production such as reaction and purification, and combines them according to the product to be manufactured, enabling continuous production. Modular production is expected to solve the problems associated with batch production, improve engineering efficiency, achieve high-mix low-volume production, shorten product launch times, make production facilities flexible, and improve energy efficiency (Figure 1).

Figure 1 Reasons for shifting to the modular production system

Configuration of the Modular Production System

The modular production system consists of multiple manufacturing modules and common parts⁴⁵.

The modules are incorporated into an infrastructure (or a backbone) that addresses the requirements of specific functions such as water supply and drainage. They are connected to plumbing, and also integrated into the automation system through power and communication lines. Standardized interfaces and data structures enable this system configuration (Figure 2).

Figure 2 Basic configuration of the modular production system

STANDARDIZING AUTOMATION ENGINEERING: MTP

NAMUR, a user association of automation technology and digitalization in the process industries, is promoting the international standardization of the module type package (MTP) as an automation engineering standard for modular production systems.

Module Type Package (MTP)

The MTP is a standardization framework that enables interoperability and automation engineering for Plug and Produce, in which multiple manufacturing units are modularized and connected (Figure 3). A project to develop MTP specifications was started in 2012, led by NAMUR. Figure 4 shows the engineering flow based on the MTP. In the MTP, the functional description of each operation unit is modularized as an MTP file. When combined into a production line, these modules can improve the engineering...
efficiency of small and medium-scale production plants. Modularized functional units are easy to apply to other cases. By using proven modules it is possible to avoid troubles in the initial stages of engineering development, greatly reducing the time and cost.

The MTP is currently under development in Germany as VDI/VDE/NAMUR 2658 series. In 2019, “Automation engineering of modular systems in the process industry - General concept and interfaces”\(^1\) based on VDI/VDE/NAMUR 2658-1 was proposed by Germany to the IEC as a new work item. SC 65E/WG 14, a subcommittee under IEC TC 65, is in charge of its international standardization and is organizing discussions.

Field Test of MTP

Proof-of-concept projects for MTP are underway with the help of user companies. For example, several automation suppliers including Yokogawa worked together to integrate an MTP cooling system package into a conventional production facility at Evonik Industries’ pilot plant in 2018. In this cooling system package, MTP files described based on AutomationML (IEC62714), which is a standard data format for engineering tools, were read with Yokogawa’s MTP import tool, and some of the graphics on the human machine interface (HMI) were generated automatically. Through this field test, we confirmed that the MTP can reduce the man-hours required for engineering the HMI.

Reducing Man-hours of Engineering Work

MTP files are a crucial element to improve the efficiency of engineering of manufacturing modules. MTP files contain the engineering information of modules in a common form. This information is used to integrate engineering among modules.

The MTP file is based on the AutomationML model. For the HMI, the file describes device symbol and function information, device tag names, location information of the device on the HMI, and connection information. Based on the device symbol and tag information in the MTP file, the insertion of graphics and the mapping of tags are automatically performed on the HMI. In the field test, we confirmed that the man-hours for the four engineering tasks shown within the dashed lines in Figure 5 were significantly reduced compared with conventional HMI engineering.

Standardization of MTP

The MTP is currently under development in Germany.
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with economic growth, the New Energy and Industrial Technology Development Organization (NEDO) promotes the Strategic Innovation Program for Energy Conservation Technologies, and Yokogawa has been involved in various projects. The iFactory is one of such projects under the Cooperative Theme-setting Scheme. The iFactory aims to develop a configurable, modular manufacturing facility that uses a batch continuous production method combining a continuous synthesis method and a batch production method.

Development of the iFactory is underway to reduce energy consumption and waste during the manufacturing process for functional materials, to save manpower to cope with the declining workforce and enhance cost competitiveness, and to achieve on-demand production that produces the necessary goods when needed.

Configuration of iFactory

The iFactory consists of a manufacturing module called “iCube,” which houses the operation units in a 2.3 m³ cube frame, and a service system called “iConnect,” which connects iCubes, supplies power and water, and drains wastewater. A production line is built by combining iCubes and iConnects (Figure 6).

Benefits of iFactory

The position and size of piping and electrical system connections are standardized in the iCube and iConnect, making it easy to configure a production system and connect piping and other components. This easy rearrangement helps quickly switch items to be manufactured, thus supporting on-demand production.

Since units for various operations such as reaction, washing, and solvent exchange are housed in a cube frame, the iCube can perform a series of processes from inputting raw materials to packaging reactants in a continuous production system. Conventionally, intermediates are separated and purified at each stage in the batch production system. The iCube can solve the problems related to this repetition, such as large energy consumption, excessive load on workers, and large amount of waste. Energy consumption is expected to be reduced by about 80% and waste by 30-40% compared to conventional methods.

Yokogawa’s role in iFactory

By consolidating the technologies in their respective fields (Table 1), the eight companies are working together to develop modules and an automatic analyzer for practical use (Figure 7). Yokogawa is developing an overall control system by taking advantage of its engineering strengths accumulated in various industries⁶⁻⁷.

Table 1 Roles of the eight companies

<table>
<thead>
<tr>
<th>Company name</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Takasago Chemical</td>
<td>Developing a control system, manufacturing execution system (MES), laboratory information management system (LIMS), and energy management system (EMS) for the iFactory pharmaceutical manufacturing equipment</td>
</tr>
<tr>
<td>Mitsubishi Tanabe Pharma</td>
<td>Developing unit operations for the displacement concentration process</td>
</tr>
<tr>
<td>Konica Minolta Chemical</td>
<td>Developing unit operations for the continuous extraction process (oil-water separation and washing)</td>
</tr>
<tr>
<td>Yokogawa Solution Service</td>
<td>Developing a control system, manufacturing execution system (MES), laboratory information management system (LIMS), and energy management system (EMS) for the iFactory pharmaceutical manufacturing equipment</td>
</tr>
<tr>
<td>TEC Project Services</td>
<td>Designing and developing the iCube modular reaction system, which performs continuous liquid separation, continuous solvent replacement, continuous crystallization, and continuous solid-liquid separation, among other unit operations in the iFactory pharmaceutical manufacturing equipment</td>
</tr>
<tr>
<td>Taisei Corporation</td>
<td>Developing the reconfigurable modular type batch continuous filtration dryer and continuous filling device, and constructing the iFactory frame and service system</td>
</tr>
<tr>
<td>Shimadzu Corporation</td>
<td>Developing high-performance liquid chromatographs for the iFactory pharmaceutical manufacturing equipment</td>
</tr>
<tr>
<td>Mitsubishi Kakoki</td>
<td>Developing the reconfigurable modular type continuous filtration machine and continuous dryer, and developing transfer mechanisms from the filtration machine to the dryer</td>
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FUTURE DEVELOPMENT

There are growing expectations for modular production systems, such as the MTP and the iFactory described in this paper. For these systems to be used globally, it is necessary to create a business ecosystem, including relevant international standards, compliance with regulations and standard certifications, as well as expansion of the lineup of modules. International standards for automation engineering defined by MTP are currently under development. The iFactory is moving ahead toward module implementation and commercialization in Japan. For global expansion, we should monitor the trend of international standardization of the MTP and other systems and align with that trend. Yokogawa will continue to actively participate in the development of standards, provide its findings obtained in the iFactory project, and contribute to standardization.
CONCLUSION

Modular production systems are attracting attention for the manufacture of functional chemicals. This paper outlined the characteristics, standardization, and trends toward practical applications. Yokogawa will continue to contribute to international standardization and proof-of-concept to meet the expectations of customers and achieve manufacturing that can flexibly respond to market changes.

REFERENCES

(1) Technology Strategy Center (TSC), New Energy and Industrial Technology Development Organization (NEDO), Drawing up technology strategies in the field of functional chemical manufacturing processes, TSC Foresight, Vol. 31, 2019 (in Japanese)

(2) NAMUR, NE148: Automation Requirements relating to Modularisation of Process Plants (Ver. 2013-10-22), 2013

(3) VDI/VZDE/NAMUR 2658-1, Automation Engineering of Modular Systems in the Process Industry - General Concepts and Interfaces, 2019


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