The concepts and components of the smart factory

Koncepcje i elementy inteligentnej fabryki przyszłości

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The paper illuminates the innovation in software – technical issues related to the concept of intelligent factory presented at TMTS show (Taiwan 2016). Programs and systems for monitoring and management of machines and production lines. And independent actions taken by machine manufacturers to adapt their products to the idea of Industry 4.0.
KEYWORDS: Industry 4.0, machine CNC monitoring and supervision, sensors

It seems that the concept of Industry 4.0 (in Poland also called Przemysł 4.0) is becoming a global standard, to which all the major manufacturers of machinery and equipment are trying to join. Theoretically, this idea consists in full integration of production / manufacturing with broadly understood communication technologies. The effect of introducing this concept is to be intelligent / smart factories where employees, machinery and processes are effectively coupled through information technology. The main objective of these activities is to increase the use of resources (reduction of production costs), to achieve the stability of production and to make the product offer more flexible [1]. So these innovations are supposed to contribute to reducing the resources and time spent on production.

Industry 4.0 is being implemented in two ways - through appropriate hardware systems (drivers, controllers, sensors), providing a variety of manufacturing data, and the software systems responsible for transmitting, processing, archiving, and requesting. The paper presents such products offered by manufacturers from Taiwan.

Machine tools

Of many machine tools presented, the five-axis vertical hybrid iGT-800AM (Tongtai brand) was paid attention. It is intended for the aerospace and automotive industries. In addition to typical machining (five axes), it also enables laser and surface heat treatment (Figure 1). All operations are performed on one machine and one attachment. The appropriate head is taken from the magazine and fastened to the spindle. According to the manufacturer, the typical application of this specialized machine can be the rapid repair of damaged parts of machines and devices.

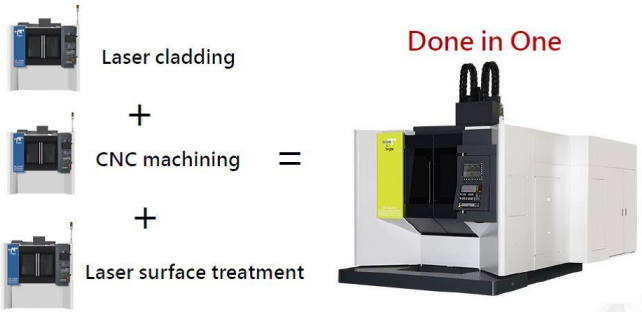

Fig. 1. Tongtai iGT-800AM hybrid machine tool (source: www.tongtai.com.tw)

The issue of heat generation in the process and by working components of the machine (thermal deformation) is very important. Habor offers specialized cooling systems for spindles, rolling bolts, linear drives, coolant and hydraulic power supply systems (fig. 2).

Fig. 2. Habor special cooling module (source: www.habor.com)

Advanced control based on digital PID controllers and inverters allow the coolant temperature to stabilize within ±0.1 °C. These systems can directly cooperate with NC over Ethernet or, in the case of older machine tools, via the RS-485 interface [2].

CNC controllers

An interesting offer was proposed by Taiwan ITRI - Industrial Research Institute (with its laboratories also in Europe). The newly developed L2100 CNC controller (fig. 3), featuring two independent processors (1.6 GHz-

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HMI and 0.8 GHz-Kernel), was able to control up to 16 digital axes with a 1 µm programmable resolution, with 1 ms of software loop. Communication with drives is via an EtherCat network. The controller's calculation capabilities allow for simultaneous control of the milling center and, at the same time, a six-axis robot (traditional, articulated or parallel). The manufacturer, appreciating the flexibility and popularity of the global data exchange standard OPC UA [3], implemented a suitable software server in the driver structure, which greatly facilitates the data exchange between CNC and production control environments [4].

Fig. 3. CNC L2100 type controller developed by ITRI (source: www.itri.org.tw/eng)

Syntec is a manufacturer of NC controllers for turning centers, milling and robots. Its own control software runs on Windows CE, which, according to the company, allows the driver to be named an open architecture system (fig. 4). Syntec provides tools for self-configuring the HMI panel by the end user. For communication with drives, a special Syntec serial bus (Mechatrolink) is used to enable full online diagnostics [5]. Interesting property of this controller is its preparation for direct cooperation with video systems. The camera image analysis (up to four) is used to orientate the workpiece in space and to work out the correct offset (offset or angle of rotation) for the tool. The manufacturer declares that this ensures an increase in the precision and quality of the treatment.

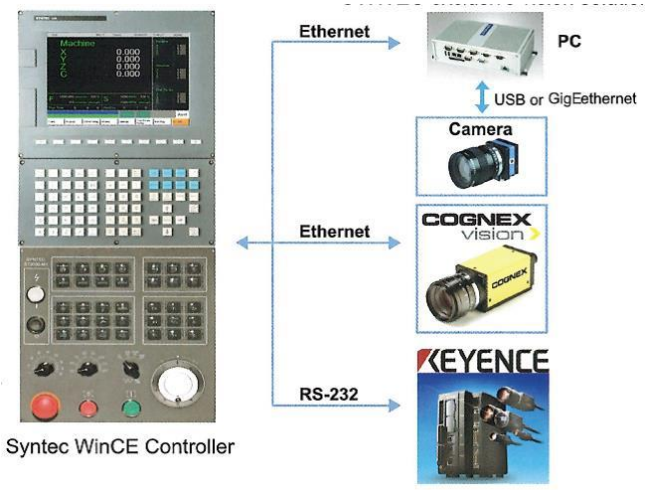

Fig. 4. SYNTEC 21MA CNC Controller (source: www.syntec-club.com)

Another example of a machine tool manufacturer that proposes its own NC controller is Chevalier. It uses the hardware core of the Fanuc controller, which adds interface and control software, the SMART-III driver (fig. 5). With a view to facilitating and enhancing intuitive operation and reducing operator training time required, the company promotes the maximum use of graphics and animations in the HMI environment.

Fig. 5. Chevalier CNC surface grinding machine (source: www.chevaliertw.com)

Goodway also installs its own CNC machine (GLinc 350) in its own machine tools. It is a very important issue - especially in industrial conditions where a wide range of products is manufactured - the company considers avoiding collisions (object-object, handle-object, etc.) and counteracting them. The controller is constantly monitoring and controlling the position of all moving parts and the tool path, and in uncertain cases, tries to take steps to avoid a dangerous situation (fig. 6). Very advanced 3D simulation and machine tool prediction are used. This ensures a collision-free treatment and a substantial (about 30%) reduction in program machining time before production begins.

Fig. 6. Goodway GLinc 350 CNC driver (source: www.goodwaycnc.com)

Software

Popularly used by manufacturers of machine tools is the installation of commercial NC program drivers in the commercial NC environment. Such software is intended for a particular machine model. It allows the operator to observe specific processing parameters (drive and spindle loads, tool status, machining time, etc.), and also facilitates manual programming (including calculators, tool management, special functions).

An example might be KAFO. Similarly, YCM operates, which proposes a software overlay to the CNC controller. The application is called iProsMX, and on the functional-graphic side, it is similar to DMG Mori's Celos interface (fig. 7). With support for Ethernet, one can collect and analyze data from individual machine tools. Smart Factory supports basic NC drivers (Siemens, Fanuc and Heidenhain). The scope of presented and processed data depends on the type of user and offers the following charts:

- for user - product execution times, current machining status, number of pieces, etc.,
- for production - the executed order, the state of its execution, the condition of the machine park, etc.,
- for management - use of machine stock, efficiency of individual machines, production, tool management, etc.,
- for service - machine condition, diagnostics, power consumption, necessary inspections, etc.

The company also offers i-Operation Plus II software. It is a software overlay for the NC driver, which extends its functionality for tool management, tool automation, object probe support (inspection measurements), periodic maintenance, etc. Additionally, YCM has its own remote machine status monitoring system i-Direct. One option is to support mobile devices as portable monitors for operators.

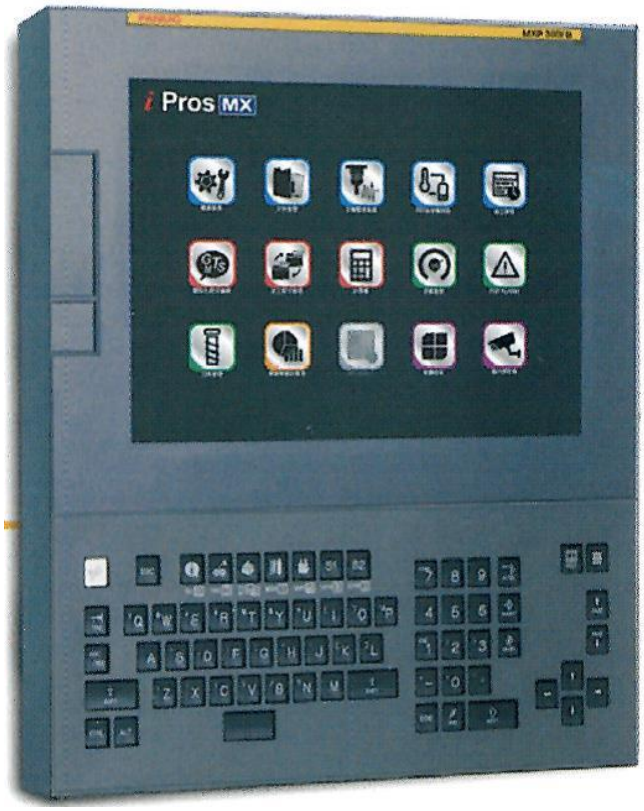

Fig. 7. YCM IProsMX driver (source: www.ycmcnc.com)

CAMPRO, a manufacturer of machine tools (freewheeling centers), proposes additional software for remote monitoring of machine status via Ethernet and mobile devices (smartphones). It is possible to save all NC messages and variables as well as current or future analysis. An interesting option is to support the operator while performing geometric measurements. The e-Management environment offered (fig. 8) allows direct integration into the IT system of measuring tools (scanners, micrometers, etc.) equipped with RS232C or USB interfaces. Recorded measurement results may be shared with other systems (e.g. QMS) or processed on site.

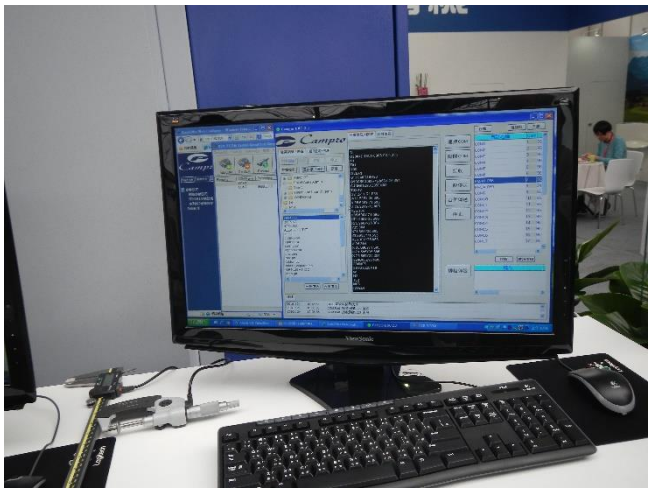

Fig. 8. Campro e-Management environment (source: www.campro.com)

The manufacturer of five-axis, large-sized portal milling machines - SIGMA CNC - in its activities and products (fig. 9) is of the opinion that to achieve the highest quality product on a cutting machine, five main requirements must be met:

- machine tool design - high rigidity of the structure, resistance to temperature changes,
- spindle - should be high rotation, rigid, with minimum radial and axial thrust,
- selection of cutting tools,
- precision CNC controller,
- TPM (total productive maintenance) program of the production manager.

Fig. 9. The Sigma SCR-H five-axis milling machine (source: www.sigmacnc.com.tw)

In order to improve the quality of the workpiece surface in the rotary head on the spindle, a standard sensor for monitoring vibration levels is installed on the spindle (fig. 10). If the permissible vibration level is exceeded, the controller modifies the spindle speed until the amplitude is reduced. The company has developed software (superCUPID) that allows remote access to the NC controller of the machine. It performs six subtasks, allowing to: view alarms and messages, work status and current position coordinates, manage program files (transfer), view tool parameters (offset), make backup copies of machine parameters, access PLC fields and diagnostic information.

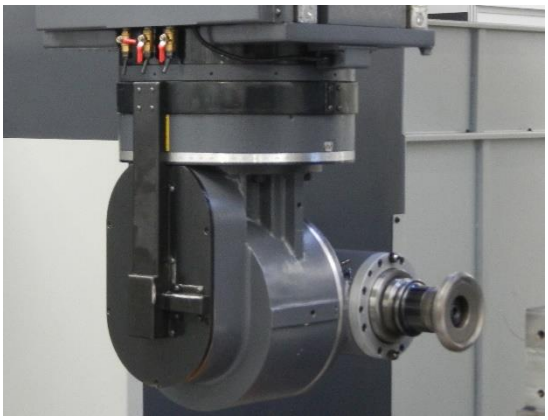

Fig. 10. Head with triaxial vibration sensor installed (Sigma SCR-H milling machine)

The Tongtai Group - manufacturers of advanced imaging machines - promotes their own TIMS (Tongtai Intelligent Manufacturing System) software for machine tools and other NC machine tools (Siemens, Fanuc, Mitsubishi, Heidenhain). It is an IT system that supports operations related to product management, increases the efficiency of machine utilization, improves machining quality, etc. It consists of five subsystems: production management, intelligent machine monitoring, tool management, product management, service management. In total, 26 individual functions are realized. All information is kept online, retrieved from the machine tools, processed and presented (fig. 11) in the form of reports. In the event of a failure on the operator panel, a spatial drawing of the machine is presented along with the relevant instructions and catalog cards of the damaged component and the recommended procedure for the removal of the defect.

Fig. 11. TIMS - machine tool management system created by Tongtai Group (source: www.tongtai.com.tw)

VMX's advanced research environment for VMware's proprietary software tools and machines has also been proposed by the advanced VMX programming environment. It allows to prepare the own virtual machine, for example, with additional sensors (vibrations, acoustic emissions), monitoring and optimization systems, and production monitoring systems. The application is installed in the structure of the NC controller and integrated with the control software. For ease of communication, it is possible to use structures such as OPC UA, SQL, and IoT [6]. VMX Platoon supports NC drivers from leading manufacturers (such as Siemens, Heidenhain, Fanuc and Mitsubishi). It is also possible to use mobile devices to communicate with the NC controller.

Some companies provide customers with a toolbar remote control environment with a special application programming interface (API) that allows for direct reference to system variables of the machine's NC controller. An example is the MillStar manufacturer using Syntec CNC controllers [7].

It should be borne in mind, however, that the introduction of new information technologies related to the idea of Industry 4.0 is unfortunately also fraught with unfavorable phenomena. Broad use of the network as a communications medium, data processing in cloud computing, and the provision of computers and drivers creates a vulnerable environment for cyber attacks, computer viruses, etc. Industrial devices equipped with computer control systems are not standardly protected from fraudulent access or fraud. Many research institutes carry out activities to address these dangers and to introduce trusted methods of data exchange through industrial automation systems. They focus on software

issues, and they suggest the use of specialized hardware modules responsible for message filtering, call encryption, and other required or useful security features.

Safety of machine tools and machines remains an important issue. There are three main areas of it, referring to:

- construction and kinematics of machine tools and intelligent systems,
- CNC controllers and drivers,
- information systems, control and verification procedures.

Currently, all machine tool products meet the relevant standards as ISO 23125 (machine tools), IEC 60204-33 (electrical equipment), ISO 11161 (components and systems for industrial automation), ISO/TS 15066 (co-workers and humans), IEC 61508 Functional safety) and ISO 13849-1 (reliability and safety monitoring).

Modern manufacturing systems and their components (such as databases, cloud computing, drivers, remote applications, smartphones, communication modules, wireless networks) require periodic updates (software installation, data exchange to the Internet, etc.). This may reduce their safety. Traditional systems (CNC, PLC, etc.) - done in closed architecture - do not require such actions. Manufacturers perceive this problem and therefore conduct intensive research to develop safety standards and procedures for intelligent manufacturing systems.

Sensors

The sensors for accurate and reliable measurement of interesting sizes and variables are, of course, the basis for precise monitoring of the process and condition of the machine tool. Lion is a manufacturer of capacitive displacement sensors. They can be used in ultra-precise measurements. In the most advanced form (fig. 12), a measurement of 10 µm with a resolution of 0.06 nm is possible (the measurement area is within a circle of 0.5 mm diameter). Typical applications include measurements of displacement, material thickness or vibration. The company also offers a similar distance measurement system. However, it uses the phenomenon of magnetic field generation during the induction of eddy currents in the material (fig. 13). In the measuring range

Fig. 12. Lion's displacement sensor (source: http://www.lionprecision.com)

Fig. 13. Lion's magnetic displacement sensor (source: www.lionprecision.com)

of 0.25 mm, the maximum measurement resolution is 0.4 nm at 100 Hz. For comparison, advanced touch sensors (Magnescale) offer a measurement range of 5 mm and a measurement resolution of 0.1 µm. According to the latest trends, sensors are equipped with industrial network modules (EtherCat or CC0Link V2) and can directly interact with PLC (CNC, CNC) machines.

These sensors were used by Lion in the comprehensive spindle error analyzer (SEA). The test takes place in three axes with an accuracy of 1 nm. Non-contact measuring method allows dynamic analysis at various rotational speeds. The software can detect bearing errors, improper preload, vibration, temperature deformation, resonance frequencies, etc. [8].

It is not always possible to install all the required or anticipated sensors at the machine building stage. One example of the use of measuring systems on machine tools is the Yinsh product. This is a specially designed (patented) axial force sensor (fig. 14). It is installed as a washer for the precision nut on the spindle setting unit. Static measurement is possible - axial force is developed during pre-tensioning of the spindle (stability of the selected values) - and dynamic measurement during machining. Various sensor sizes are available for use in nuts ranging from M40 to M170. The maximum force measured reaches 4000 kG.

Fig. 14. Yinsh - axial force sensor (source: www.yinsh.com)

In Industry 4.0, a key element is the efficient communication that enables the acquisition of various data. The concept of the Internet of Things (IoT) and the Industrial Internet of Things (IIoT) [9] is to serve this purpose. On the market, there appear products designed to facilitate the creation of occasional industrial networks. Examples include ICP DAS products. It produces hardware hubs with a built-in powerful microcontroller (with firmware) and a variety of communication processors. The idea is to create "acquisition islands". It is possible to attach different sensors and communicate via data communication interfaces to the master system. OPC UA and MQTT are used for this purpose. This is a method of communication by writing and extracting application-specific data (messages) without the need to create a private / dedicated connection. It definitely accelerates the integration of various Class IIoT devices.

Conclusions

According to the described examples, the concept of Industry 4.1 is strongly represented among Taiwanese manufacturers of imaging and processing equipment. Software and hardware proposals clearly indicate the acceptance and promotion of this idea. However, it should be noted that the proposed products are rather intended for large-scale customers with highly automated production. It seems that not every production plant has to implement the concepts of Industry 4.0. This should not be obligatory. There are many proposals for different industries that use specialized software to facilitate the exchange of information and, consequently, increase the efficiency of production. There are many small and medium companies offering highly specialized solutions (hardware and software). Introducing them can also result in a significant increase in the use of plant resources and a decrease in manufacturing costs without having to change the whole structure of the company in line with the idea of Industry 4.0. It is also worth noting the possibility of self-developing software. According to the Fraunhofer IPA Research Institute [10], it is the most appropriate and thoughtful, and can result in up to a 75% reduction in manufacturing costs at the plant.

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