

## MONITORING AN ELECTRIC MOTOR INTEGRATED IN AN AUTOMATED SYSTEM

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**Abstract:** *This paper presents the progress from the field of integrated automation and safety systems that assure a well functioning of manufacturing equipments. Nowadays, many devices have sensors that monitor operational parameters. This advancement was made in order to protect the equipment and to prevent them from malfunctioning or stopping. Considering that equipments work in real time, the system response is essential and must be instantly or with a response time as low as possible. Adopting an appropriate solution requires knowledge of automation as a complete development process, technological restrictions and also designing and choosing a solution so that the conceptual structure and enabling automation equipment meets the performance requirements of the system. Through this work it is intended to reach further to new solutions for the automation of a integrated system, the study of an active control of the parameters from a drive system of machine tools and programming of an automated system that has integrated logic. As an application, it is presented how a temperature sensor was implemented in a automated system in order to prevent the electric motor to overheat and malfunction.*

**Key words:** *advanced monitoring, PLC, integrated manufacturing, TIA Portal, programmable logic.*

### 1. INTRODUCTION

Providing a monitoring system to a manufacturing process is important. This way the operator has more tools to verify the devices and prevent problems before they appear. This paper makes an overview of advancements in monitoring systems of devices integrated in manufacturing processes.

The Integrated Concept occupies an important place in contemporary scientific and technological landscape and involves, directly, the process of implementation of new technologies, new organizational structures and management in manufacturing enterprises, conditioning reorganization, revitalization, flexibility and increased economic competitiveness of these economic units [1].

Design and manufacture integrated with the help of the computer are found in many companies, regardless of size, given the complexity of products to be fabricated, the technology which involves determining product cost and the need to build a database which also includes management systems [2, 3].

### 2. MACHINE TOOLS AND MANUFACTURING SYSTEMS

Some of the latest machine tools and flexible modules are built as being modular, covering an increasingly advanced range of optional technological need.

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Table 1  
Adaptability issues in integration of CIM systems [4]

Level	Problems
Strategic	The concordance between marketing strategies and production strategies
Organizational	Structure, Communication
Behavior	Leadership, Teamwork, Motivation, Collaboration, Stimulation
Technological	Networks, Communication Systems, Databases
Operational	Design, Production of planning and system control , Accounting

Machine tools go from machine tool with numerical control to production systems integrated with the help of the computer. Considering that these devices are complex and expensive, they need monitoring systems that prevents them from damaging.

An organization must develop a strategy that suits the best environment in which it operates. Details on each of these aspects are presented in Table 1. The monitoring part should be integrated in the technological level and it should be given an increased attention.

The integration of computers brings the benefit of a fast and error-free manufacturing. A main advantage of CIM is the possibility to create automated manufacturing processes.

In a CIM system all areas connected to manufacturing are linked through the computer, providing a complete monitoring oversight of all operations.

### 3. MONITORING SYSTEMS

There are researches that follow the integration of tool and machine condition monitoring with CNC control by permitting access to internal signals in the numerical controller, such as motor power, motor current, or additional measured signals like position and vibrations [6]. Also there are some researches that study integration of various monitoring functions in one system. However, most monitoring systems are made as a simple, stand-alone solution [7]. As for future, in order to meet the end user requirements, monitoring systems will have to permit real time supervision of all machining process, machine, and produced part parameters. The tendency is that the procured information will be used for online control of production process.

Also, virtual systems can be created in order to collect real time data from real systems and make simulations to observe possible failures. Considering that the systems are automated, they can change the parameters of the real systems.

In order to implement such a complex monitoring and supervision systems, two important issues must be solved. First issue is obtaining a real time, reliable information on state and condition of the machine tool and the manufacturing process. The second one is to create a system which should analyze the obtained data in order to observe a problem [8]. Also, the system must be the one which facilitates a decision that address to the discovered problem, tries to avoid losses and reduce the overall risk.

Table 2

**Monitored parameters and solutions to problems in manufacturing system [10].**

Monitored object	Examples of parameters that can be monitored
Machine tool	<ul style="list-style-type: none"> <li>Machine tool or critical components condition monitoring</li> <li>Thermal errors, geometric and dynamic parameters</li> <li>Vibrations, temperature, acoustic emission</li> <li>Proper operation of mechanisms</li> <li>Maintenance activities</li> <li>Time of work (preparation, processing, breakdown, maintenance)</li> </ul>
Machining process	<ul style="list-style-type: none"> <li>Tool condition monitoring</li> <li>Temperature, vibrations, acoustic emission</li> <li>Process efficiency</li> <li>Process parameters</li> </ul>
Workpiece	<ul style="list-style-type: none"> <li>Geometry (dimensions, tolerances)</li> <li>Surface parameters (roughness, quality, geometric parameters)</li> <li>Material parameters (temperature, hardness, stress)</li> <li>Manufacturing data: time (preparation, processing, waiting), machine and tool(s) number(s), operator, etc.</li> </ul>
Monitored object	Examples of decisions that can be taken to solve discovered problems
Machine tool	<ul style="list-style-type: none"> <li>Compensation of dimension and geometry changes caused by temperature changes or process forces.</li> <li>Changes in process parameters, eg., to avoid vibrations or increase temperature.</li> <li>Starting of maintenance activities.</li> <li>Testing to analyse discovered problem or to check proper operation after maintenance.</li> <li>Emergency stop, eg., in machine breakdown.</li> <li>Working with limited functionality.</li> <li>Proposing action plan to solve the problem.</li> </ul>
Machining process	<ul style="list-style-type: none"> <li>Process optimisation – process parameters changes.</li> <li>Changes in process parameters, eg., to avoid discovered problems or minimise losses.</li> <li>Support operator by suggestion of optimal parameters suited to actual process condition.</li> <li>Emergency stop, eg., in the case of tool breakdown.</li> <li>Proposing action plan to solve the problem.</li> </ul>
Workpiece	<ul style="list-style-type: none"> <li>Selection of optimal process parameters.</li> <li>Recording history of manufacturing: machines, tools, parameters.</li> <li>On-line optimisation of process parameters according to measured part parameters.</li> <li>Optimisation of production parameters – time, schedule, batch size, etc.</li> <li>Proposing action plan to solve the problem.</li> </ul>

An operator, which is supported by the IT system, must be able to take all this decisions, but in order to create a automated system, the decisions must be taken automatically [9].

An important problem that is met in condition monitoring of process, machine tool and workpiece is the large number of variable parameters. In the case of using a high-speed tool or workpiece rotation, data must be sampled with a high frequency [11]. This data is stored locally and analyzed by dedicated algorithms in order to select only the important information. With the use of this information, certain actions can be made. Table 2 presents examples of parameters that are possible to be monitored in a manufacturing system together with solutions that can be used in order to overcome the problems.

#### 3.1. Monitoring systems used for maintenance

An important branch of monitoring application is represented by the maintenance systems. At this moment of technological advancement, manufacturing systems must have almost zero breakdowns. It is important to have a reliable system that usually works in a just-in-time environment, without having additional reserves [12].

One of the important issues met in the development of monitoring systems set for maintenance is the necessity of providing real-time information regarding the status of one machine and one process [13]. A reliable maintenance system needs a monitoring analysis over an online network. It should deliver predictable information regarding problems that are possible to appear, lower functionality, or the trend of the breakdowns that can appear in the near future [14].

The concept of E-maintenance is developed under the umbrella of Internet and cloud computing [15]. It is based on systems communicating over Ethernet by exchanging information. This kind of maintenance will integrate supervision and monitoring into one complex system which can supervise an entire production floor along with the supply chain [16, 17].

Modern monitoring and supervision systems dedicated to different manufacturing processes should have many different functions such as data collection, analysis and decision proposing functions. Therefore, the operator does not need much background knowledge about engineering, he only needs the information provided by the system, take a decision and execute an appropriate action [7]. Creating such an advanced system is a complicated task. Usually, a powerful IT company is needed to integrate the monitoring into the advanced manufacturing line. With the help of a programming logic, control functions must be implemented in order to allow the user to take actions according to identified problems [18].

#### 3.2. Data acquisition

Usually, data acquisition is made through special cards that collect information from sensors in real time. The sensors acquire data from a certain part of a process or a machine element. Then, collected signals as information, they are filtered and prepared for further analysis.

It is difficult to distinguish needed data from information that also has false disruptions from the environment and has nothing to do with machining process.

### 3.3. The evolution of monitoring

Monitoring process evolves with a rapid pace. The tools and methods, combined with the new sensors, computing power and computing protocols permits a more efficient acquisition of information [19].

Processing and analysis of recorded data is based on indirect and direct measurements. Different parameters like cutting forces [20], drives load, current, forces, temperature, acoustic emission, sound signals, vibrations, noise and surface acoustic wave or torques can be measured and analyzed.

To acquire data, various types of sensors are used: optical, piezoelectric, mechanical, laser, etc. [21]. The trend is to make monitoring easier by implementing sensors in machine parts, chucks, drivers and tools. Research based on this kind of approach was done by Sortino M. [22] and Klocke F. [23].

## 4. EQUIPMENT USING PROGRAMMABLE LOGIC

The concept of PLC stands for Programmable Logic Controller and it is a kind of digital computer used for automation of industrial processes such as control of machinery from a factory assembling line.

The PLC performs two main tasks in the automation process:

- measure, which in this case involves monitoring of process condition by acquisition of data from inputs through sensors, buttons, limit switch, etc.. from the process's state variables [24, 25];
- control, which involves processing the information from the input and generating the necessary commands to actuators from the automated process, according to a specific program [26].

A PLC can be defined as a specialized system designed to analyze sequential and combinational logic problems, simulating logic control structures by a resilient program configuration [24].

Considering that PLCs are flexible and programmable, they can perform different tasks from monitoring to maintenance jobs. Programming maintenance jobs can assure keeping the devices in a good condition and extending their life.

The structure of an automated process using a PLC can be synthesized by the block diagram shown below (Fig. 1).

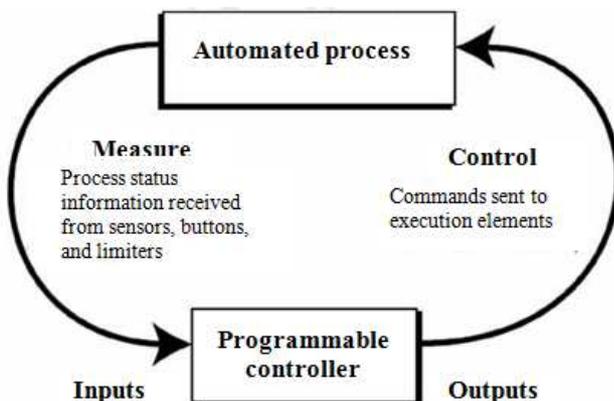


Fig. 1. Structure of an automated process using a PLC [3].

### 4.1. Interconnection of PLCs

To run more complex processes it is possible to connect multiple PLCs to a central computer. An example of such a system is the system SCADA. SCADA stands for Supervisory Control and Data Acquisition. The term refers to a comprehensive system of measurement and control. SCADA automation is used for monitoring and control of chemical processes, physical or transport. The term SCADA usually refers to the command center that monitors and controls an entire production area. Most of the operations are executed automatically by the RTU (Remote Terminal Units) or the PLC. A system like this is very complicated and usually has a complex diagram.

The supervisory system may be combined with a data acquisition system by adding the use of coded signals over communication channels. This is made in order to acquire information about the status of the remote equipment for display or for recording functions. It is a type of industrial control system (ICS). Industrial control systems are computer-based systems that monitor and control industrial processes that exist in the physical world. SCADA systems historically distinguish themselves from other ICS systems by being large-scale processes that can include multiple sites, and large distances [25].

Through sensors measurements, thresholds can be set for the safety of the operator and of the equipment. PLCs can be programmed to read the sensors and react in case of system malfunction.

## 5. AUTOMATION STAND

Due to the high memory capacity of the autonomous console, off-line programming solution typically uses complex programming software which has multiple programming possibilities due to a complex graphic user interface. Simulation facilitates the possibility of testing the created program. One such program is a software from Siemens called TIA Portal, which can be seen in Fig. 2.

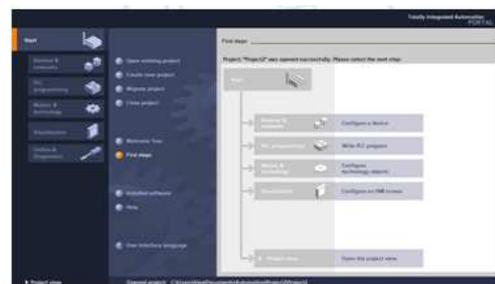


Fig. 2. TIA Portal software (Siemens).

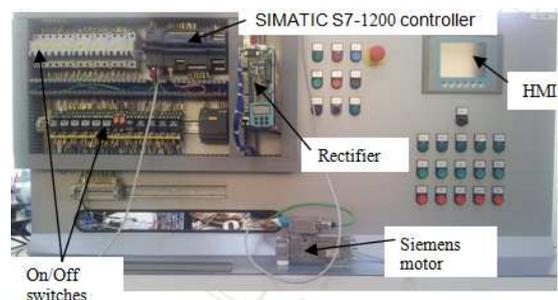


Fig. 3. Automation stand (Siemens).

This is a complex programming software which tests and simulates different variants of PLC connections. By contrast, on-line version uses a minimal software, with reduced programming, usually limited to the introduction of words in a command line environment, without having a graphic user interface [26].

Further, a Siemens motor 1FK7022-5AK21-1DG0 will be observed. The motor has 6000 RPM, 1.8 kg, 0.37 kW rating power and an input voltage of 230 V. A program will be created in TIA Portal in order to monitor the temperature of the motor and to stop it when it reaches a critical temperature. The research will be made on the equipment presented in Fig. 3.

### 5.1. Components of the stand

In order to have a valid example that can be compared to new and advanced systems, a Siemens automation was chosen. The stand that was used for the study contains latest models of automation components that have best firmware available in order to function at the maximum potential.

The SIMATIC S7-1200 compact controller is the modular, space-saving controller for small automation systems that require either simple or advanced functionality for logic, HMI and networking. The compact design, low cost, and powerful features make the S7-1200 a perfect solution for controlling small applications.

As part of the SIMATIC commitment to "totally integrated automation" (TIA), the S7-1200 product family and the TIA Portal programming software give the flexibility that is needed to solve any automation needs.

The SIMATIC S7-1200 controller solution, designed for the "compact" controller class, is comprised of the SIMATIC S7-1200 controller and SIMATIC HMI Basic panels that can both be programmed with the TIA Portal engineering software. The ability to program both devices using the same engineering software significantly reduces development costs. The TIA Portal includes STEP7 for S7-1200 programming and WinCC for designing Basic panel projects.

S7-1200 can be extended up to 11 modules and it uses PROFINET or PROFIBUS communication protocols that are specific protocols used in the automation industry because smaller information packets are transmitted with a higher speed. These protocols have a lower response time than TCP / IP protocol.

It contains a card that loads the program in order to be run and it is a compact product containing a CPU and more inputs and outputs, which are analog or digital .

On the left side of S7-1200 communication modules are available and on the right are signaling modules (inputs/outputs). The modules can be mounted horizontally and vertically. It is preferred the horizontally mount for better ventilation.

S7-1200 also contains a signaling board with inputs and outputs that can be analog or digital, a network card with RJ45 connectors and a battery board that keeps the clock active machine after machine shutdown (battery must be changed annually).

The SIMATIC S7-1200 is connected to touch panel HMI KTP 600. The SIMATIC HMI Panels can be used anywhere where it goes directly to the operation and monitoring of simple machines and equipment on site.

They are used in the most diverse industries and applications, such as in the manufacturing and process automation. HMI KTP 600 has 6" display with touch functionality for intuitive operation and applications for alarm system, recipe management and trend curve functionality. The HMI is connected with the CPU through a standard Ethernet / PROFINET connection. It has flexible scalability within the HMI family through the configuration options with SIMATIC WinCC flexible (from SIMATIC WinCC flexible 2008 SP1 Compact) and Step 7 Basic for S7-1200 usage. SINAMICS S120 is a modular drive system with servo and Vector Control. The SINAMICS S120 AC Drives especially supplement the DC/AC units with a central power in feed and a DC link in types Booksize and Chassis for multi-axis applications. 1FK7 motors are permanent magnet excited synchronous motors. The self-cooled motors are characterized by superior overload capability, ruggedness and compactness. The connection via rotatable connectors and preassembled cables ensures a flexible, fast and safe connection to the converter.

### 5.2. Connecting the automated system over TIA Portal software

TIA Portal is a software that optimizes all planning, machine and process procedures. With its intuitive user-interface, simple functions, and complete data transparency, it can connect all kinds of equipment.



Fig 4. SIMATIC S7-1200 controller.



Fig 5. SINAMICS S120 Converter.



Fig 6. Motor 1FK7022-5AK21-1DG0.

Pre-existing data and projects can be integrated or updated depending of the user needs. This software is used to connect all the equipments through special automation Ethernet protocol that is called Profinet.

Program of HMI is designed to control the RPM and visualize the motor status with the help of SINAMICS S120 Converter. The motor is equipped with a filter in order to filter the positive harmonic from the electric network. The connection between the actuator and the converter is realized by DriveCliq (the green cable) and the converter is connected to the PLC through an Ethernet cable. PC connection is via Ethernet port is done by setting the PC IP to 192.168.101.100 and the subnet mask to 255.255.255.0. Converter IP is 192.168.0.1, PLC IP is 192.168.0.2 and HMI IP is 192.168.0.3. The automation system can be utilized in two ways: manual and automatic. If one operating mode is selected, the other operating mode will not be available. On manual mode the system is operated by the buttons available on the front panel. On automatic mode, the system is operated from the HMI panel. Functioning mode or stationary mode is indicated through a green lamp and damages related through red lamp. For emergency stop there is a big red button that stops the process and to continue the operation, reset button must be pressed. For acknowledgment of convertor or motor failures fault reset button must be pressed. With the help of the potentiometer, it is possible to change the RPM of the electric motor.

From a potentiometer key a setpoint speed can be set for the motor. Motor torque limit is indicated by the dedicated green lamp. Warning lamp functions at either of the two modes of operation. To control additional or auxiliaries equipment connected by clips available that comply with the wiring diagram, there are buttons to drive in manual mode and a dedicated operator panel display.

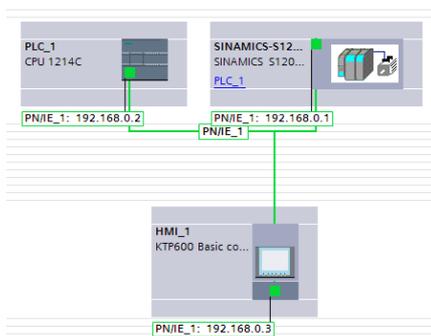


Fig 7. IP based connection through Profinet protocol.



Fig 8. HMI KTP 600 touch panel with menu for setting temperature limit.

## 6. THE TEMPERATURE SENSOR

In this case we use an external sensor thermocouple made by INOR company which specializes exclusively in this area. The temperature sensor is associated with a transmitter. The module must obtain and amplify the signal and exclude external factors, among others.

We selected a transmitter series HAPAQ-HRF-PT100 (APAQ-HCFX-HCF\_ [2]) for the measurement with a range beyond 1000 ° C, which has from 4 mA to 20 mA output. The sensor was glued to the actuator without being in direct contact, because this would affect its operation. After mounting and calibrating it, we connected it to the module input/output SM1234 PLC that we use in the project. According to the information from the back of the transmitter, it is known that it is a type K thermocouple (up to 1010 ° C) and that beyond 23 mA it no longer transmits data. The output data of the sensor is read between 9 mV and 40 mV the transmitter converts it to mA. It is imperative to have a fail-safe mechanism in order not to damage a system that can cost a lot of time and money to repair. In order to implement the fail-safe mechanism, a program was made for the S7-1200 Controller in order to reduce the RPM or even to stop the system in case of high temperature. As it can be seen in Fig. 8, the system enables the operator to set a critical temperature. When the motor reaches it, the system reduces the RPM or stops the entire procedure, depending on the operator needs. Considering that TIA Portal programming has many modes to program a PLC, to make the simulation more realistic, we propose in the future to add a time delay for the motor stop. In a real situation, a forced shutdown could damage some other components attached to the system.

## 7. CONCLUSIONS AND PERSPECTIVES

In this article the latest trends in monitoring and data acquisition were presented as results achieved by different researchers, including Sortino M. [22] and Klocke F. [23]. Latest machine tools and production systems are supervised by different sensors that have the purpose to optimize the working parameters of the devices and prevent them from malfunction or stop.

This is important especially for the systems that work 24/7 and have a workflow that has a close connection with a supply chain of other products.

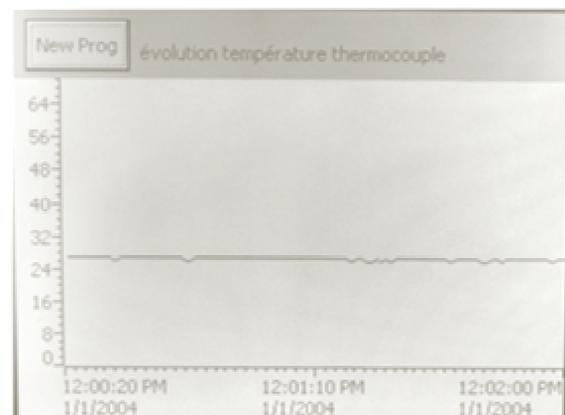


Fig 9. Representation of the temperature measured by the sensor.

TIA Portal is presented as a solution for the automation of a production system. It is a software that has an object-based programming. Through TIA Portal, PLCs are programmed to monitor different parameters and react adequately, depending on the situation. In our case, we used a Siemens stand to which we connected an external temperature sensor which is monitoring the temperature of the electric motor. Through TIA Portal, the PLCs were programmed to spin the motor at a specified RPM in order to create a reproduction of a working cycle and to stop the motor when it reaches a harmful temperature that we set.

The perspectives of this work are finding new solutions for automation of an integrated system, a study of active control of the drive system parameters that belong to a machine tool and programming an automated system with integrated logic. In the following research RPM and temperature parameters will be monitored in order to obtain a working cycle that will not affect the well functioning of the motor.

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