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REQUIREMENTS FOR IT SYSTEMS FOR AUTOMATED MARKING OF MECHANICAL PRODUCTS IN ASSEMBLY LINES

WYMAGANIA DLA SYSTEMÓW INFORMATYCZNYCH DO AUTOMATYZOWANEGO ZNAKOWANIA PRODUKTÓW MECHANICZNYCH NA LINIACH MONTAŻOWYCH

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Abstract

In many industries there is an obligation to mark the product. In case of mechanical products, such marks are most often applied to products by labelling, as well as mechanical and laser engraving. When marking, employees must remember to change the configuration of the marking machine in case of a change in the type (reference) of the product to be marked. Especially in case of products produced in short production runs, there can be mistakes made by employees and unnecessary time wasted on reconfiguring the marking machine. Therefore, IT applications supporting marking according to the selection of a product from a list or automatically based on the plan of the marked products are gaining importance. This article describes the requirements for computerised systems aimed at supporting the automated marking of mechanical products in assembly lines in companies, which in their case do not see much sense in investing in expensive universal professional software.

Keywords: production, product marking, production data recording, IT systems

Streszczenie

W wielu gałęziach przemysłu istnieje obowiązek nanoszenia oznaczeń na produkt. W przypadku produktów mechanicznych, znaki takie najczęściej nanosi się na produkty za pomocą etykiet, grawerowania mechanicznego i laserowego. Przy znakowaniu pracownicy muszą pamiętać o zmianie konfiguracji urządzenia znakującego w razie zmiany typu (referencji) znakowanego produktu. Zwłaszcza w przypadku wyrobów produkowanych w krótkich seriach produkcyjnych może dochodzić do pomyłek pracowników i niepotrzebnej straty czasu na przekonfigurowanie urządzenia znakującego. Dlatego znaczenia nabierają aplikacje informatyczne wspomagające znakowanie według wyboru produktu z listy lub automatycznie na podstawie planu znakowanych produktów. Niniejszy artykuł opisuje wymagania dla systemów informatycznych, których celem jest wspomaganie automatyzowanego znakowania produktów mechanicznych na liniach montażowych w przypadku firm, które w nie widzą większego sensu inwestowania w drogie profesjonalne uniwersalne oprogramowanie.

Słowa kluczowe: produkcja, znakowanie produktów, rejestracja danych produkcyjnych, systemy informatyczne

1. Introduction

Product marking plays an important role in industry, from production processes to transportation. In many industries, there is an obligation to mark the product. It may result from existing legal regulations, but also from the internal requirements of the company and its customers. Industrial marking must be durable and environmentally resistant in the workplace, as well as must be legible. A permanent mark applied to a product helps to trace the product in the production process, but it is also information for consumers about the characteristics of the item. In case of mechanical products, such marks are most often applied by means

of sticky labels, mechanical and laser engraving, as well as by attaching radio tags to them. During marking, employees at the final assembly station or quality control must remember to change the configuration of the marking machine in case of a change in the type (reference) of the product to be marked. Especially in case of products produced in short production runs, there can be mistakes made by employees and unnecessary waste of time on reconfiguring the marking machine. Therefore, IT applications supporting marking, according to the selection of a product from a list or automatically, based on an internal plan (list) of marked products, are gaining importance. This article describes the requirements for IT systems aimed at supporting the automated marking of mechanical products at the final assembly station or quality control. The requirements discussed in the paper are based on several years of observation and cooperation with companies, which use marking in assembly lines as well as based on gathering and analysis of companies' requirements.

2. Issues of marking of mechanical products

Currently, it is difficult to imagine logistics, sales or production without various types of detail marking, i.a. descriptions, codes, characters and serial numbers. They enable unambiguous identification of objects, as well as determination of their characteristics. For this purpose, many methods of applying these kinds of marking are used in industry. The choice of marking method is influenced by many factors. One of them is the amount of information necessary to convey, the available surface of the produced part on which it is to be contained, as well as its shape. If there is a need to apply a small amount of data to the object, the engraving method in the form of text or one-dimensional (1D) code can be used. Unfortunately, this technique will be ineffective when more information is required. In this case two-dimensional (2D) codes, like Data Matrix and QR, work well. Another important factor influencing the selection of the marking method may be the influence of the environment, i.e. to what extent it is possible to damage or get dirty the marked surface causing only a fragment of the mark to be read. In such cases, industry also uses 2D codes, which contain redundant information, thanks to which it is possible to read the complete data even when the entire image is not available. It is clearly stated in (Karrach et al., 2022). For example, Data Matrix code and QR code can still be accurately scanned even if up to 30% of its surface area is damaged or obscured. Several publications (Gu at al., 2024, Nguyen et al., 2023) have explored the redundancy and damage resistance of QR codes and other two-dimensional (2D) codes, focusing on their error correction capabilities. These studies provide insights into how QR codes can maintain readability despite physical damage or distortion. The (Dold et al., 2015, Zhang et al., 2019) papers provide an introduction and overview on serialized machine readable code applications as an information source for technical, IT and engineering teams preparing to start with traceability implementation solutions in packaging.

There are already ISO standards, which define the structure, encoding, and specifications for different coding ideas used in various industries:

- one-dimensional (1D) linear barcodes (ISO 15416:2016, 2016),
- two-dimensional (2D) label-based barcodes (ISO 15415:2011, 2011),
- two-dimensional DPM codes (ISO/IEC TR 29158:2011, 2011),
- Data Matrix codes (ISO/IEC 16022:2024, 2024),
- QR codes (ISO/IEC 18004:2015, 2015).

Several publications in journals, like Wall Street Journal and The Guardian, in 2024 discussed the transition from traditional barcodes to QR codes by brands and retailers, aiming to enhance sales and customer engagement. The articles reported on the potential replacement of traditional barcodes with QR-style codes, which can store more detailed information and enhance consumer engagement.

The choice of marking method is also influenced by the way the information is read. Depending on whether the identification process is to be fully automated or performed manually by an employee, different forms of marking are used. In any case, codes used in industry must be resistant to adverse environmental conditions (e.g. extreme temperatures, high dust, painting), as well as the ability to encode a large amount of information while maintaining a small surface area. Direct Part Marking (DPM) technologies ensure that the code is resistant to adverse environmental conditions. The main methods of DPM, in case of mechanical products, are primarily: etching, embossing, milling, laser marking, dot peen marking. 2D codes applied using the DPM method are used in the aviation, space and automotive industries (e.g. for tracking parts during production, tracking engines during services). In case of laser marking, there are now many different methods in practice that can be used to achieve high-quality marking on the produced part in different materials with different shapes. Additive 3D marking (e.g. polyjet) is currently gaining more and more interest, especially in castings (Desavale et al., 2022)

At this point, it is impossible not to mention another, very efficient technology for marking

mechanical products, namely RFID (Radio Frequency Identification) technology. It is a method that allows for contactless identification of objects using radio waves. An important feature that distinguishes RFID from optical technologies in the product coding area is the ability to simultaneously scan multiple RFID tags. As a result, this technology allows for object identification without the need for individual scanning, as is the case with optical codes, which is highly helpful when inventorying the warehouse. Industrial companies invest in this technology when the need for rapid identification or automation is a priority, as well as resistance to damage (Unhelkar et al., 2022). There are already ISO standards defined for wireless communication technologies used for identification and data transfer as well, like:

- NFC – Near Field Communication (ISO/IEC 18092:2004, 2004),
- RFID – Radio Frequency Identification (i.a. ISO/IEC 18000-1:2018, 2018).

One shall use RFID technology if long-range tracking (inventory, supply chain, access cards) is needed, from the other side one shall use NFC technology if short-range, secure communication (payments, authentication, automation) is required. In (Thanapal et al., 2017) areas of RFID as well as NFC application and effectiveness for industry were reported. The (Profetto et. al., 2022) scoping review aims to provide readers with an up-to-date picture of the use of RFID technology in health care settings. The (Report, 2022) report provides an in-depth analysis of the RFID technology market, discussing current trends, applications, and future growth prospects across various industries. The (Xin et al., 2021) article points also at disadvantages of the RFID technology for booking inventory in the industry, such as expensive equipment, low accuracy, and high business threshold. The (Kim et. al., 2019, Statler, 2016) articles outline and compare barcodes, QR codes, NFC and RFID, their various functions with regard to consumer marketing and business applications.

3. IT solutions available in industry

To generate codes, 1D or 2D, software is required. The software can convert data into syntax, which is handled by the marking machine. It can be an integral part of the marking machine or be independent. Independent software can be used with any type of marking machine, as long as it is possible to communicate with these devices via communication links (e.g. serial port, TCP/IP network port). The software built into the device is dedicated to a specific type of device. It has an internal logic that can directly generate, m.in, a data-matrix symbol for product labelling. More and more companies decide to implement interfaces in the form of process visualization (operator's panels) due to the versatility of this technology and the possibility of introducing modifications to the software itself without the need to replace the hardware. HMI (Human Machine Interface) is an industrial graphical interface that connects a machine or process with the person who operates it through a physical operator's (control) panel. Such a relationship allows employees responsible for the implementation of tasks to control the course of the process and influence it. One of the most important tasks of the HMI is to provide the operator with real-time information by visualizing the process. It allows for quick and intuitive identification of a possible problem, and thus shortens the employee's response time. "By using online and real-time systems on the HMI, a system can be obtained, that can be controlled and monitored as soon as events occur. With the system integrated HMI, all events can be observed from the monitor screen and can control the system immediately through a computer monitor" (Setiawan et al., 2019). However, HMI may not be enough technology to support more advanced processes. SCADA (Supervisory Control and Data Acquisition), on the other hand, is a computer system that allows to control complex processes and obtain data. It enables their local or remote control through the use of HMIs, which are an important element ensuring communication between devices and the user. In addition, SCADA systems allow to monitor and process the collected data and keep a record of important events and alarms. Appropriate integration of the software allows to connect to external sources of information and transfer data in various formats. "SCADA systems, are widely used in automatic management and control of producing and manufacturing processes throughout the world, reducing manpower and improving production efficiency" (Sinshaw Tamir et al., 2020). "The vast majority of today's Supervisory Control and Data Acquisition (SCADA) systems originate from the leading global manufacturers of industrial equipment characterized by their self-contained ecosystem of proprietary hardware and software solutions" (Šverko et al., 2024).

4. Requirements for the computer application for marking of mechanical products

A computer application, the purpose of which is to support the automated marking of mechanical products, is usually used on a single computer located directly at the assembly final station of a mechanical product, physically connected via a communication link with a marking machine, eventually with other

devices (i.e. measurement devices), as well as with remote database. It is best if the application does not absorb the operator too much at the workplace. Only in case of problems, the application can signal to the operator the need for intervention by indicating which procedure to follow. If the employee (the operator) uses other applications, e.g. for reporting, the automatied marking application should run in the background and only occasionally inform about the progress of the marking process. In particular, an IT application supporting automated marking is required to:

- communication with the marking machine in order to carry out the automated marking process (e.g. through the serial port protocol or TCP/IP network protocol),
- reading the data for marking from a file generated e.g. by a measuring device, or from a database, as well as saving the confirmation of the completion of marking to the database or a reporting file,
- enable manual interruption of marking by the workplace operator, e.g. due to incorrect data or other problems that occurred immediately after sending the data to the marking machine,
- enable "acknowledging", i.e. "canceling" or accepting marking errors and resuming the marking process by the user,
- enable usage of built-in procedures so that in case of a problem, one can return to normal operation without the need to restart the application or the computer itself,
- if necessary, provide feedback from external devices, e.g. measuring devices,
- in case of an accumulation of data packages (products) for marking, presentation of the queue in the form of a list, as well as to enable possibility of manipulating this queue (e.g. removal of elements from the queue along with any accompanying information, e.g. files and vice versa – deleting an unnecessary file should remove the item from the list),
- display to the user (on request) chosen process parameters and the status of individual stages of production process,
- generate an event log – in order to record the history of marking, as well as a detailed exchange of information with the marking machine itself, in order to identify possible causes of disruptions in the marking process or the causes of repeated errors,
- enable a configuration of the application by an authorized user in order to, for example, define a communication port or a configurable data chain pattern sent to the marking machine,
- enable testing of communication with the marking machine by directly generating sample marking data, without the need to read files or database content.

In the following subchapters, the main requirements for an IT application supporting the automated marking of mechanical products at final assembly or quality control stations will be discussed.

4.1. Communication with the marking machine

Without computer support, the assembly station operator would have to manually enter the data to be i.e. engraved on the product, and select a marking template. There is then a risk of mistakes, and this process is time-consuming, as well as tedious. The operator must also keep a log of the marking operations performed. The computer application in the field of automated marking of the relevant data performs all operations for the employee. The employee only needs to place the product with the right side under the marking head and confirm the readiness of the marking machine with a physical button.

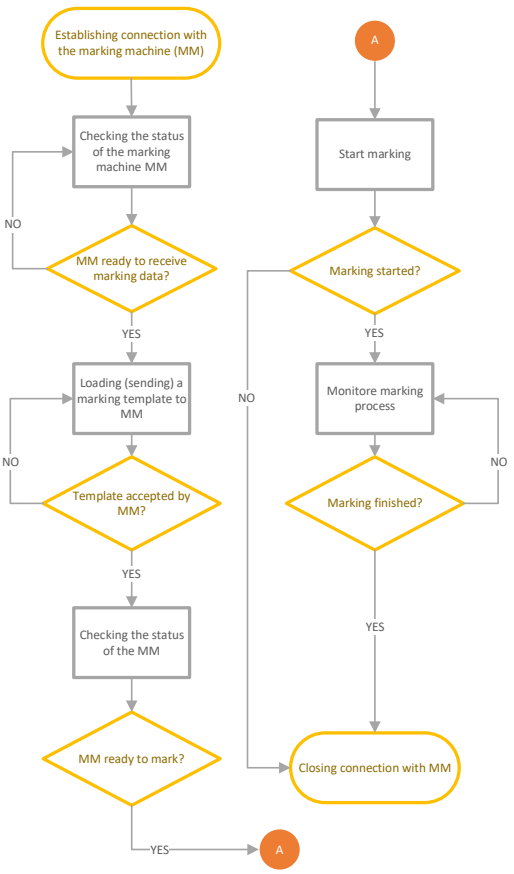

Fig. 1. Procedure of communication with marking machine [source: own development]

The automatic procedure for communicating with the marking machine should include the following steps, which are shown on Fig. 1:

- establishing a connection with the marking machine (logging in, sending a protocol message), often requiring multiple exchange of information,
- checking the status of the marking machine (whether it is ready to accept data) – the marking machine confirms or denies readiness by sending a predetermined message,
- if required, uploading (sending) a template containing texts and variables (assigned in the marking order from the network database) to the marking machine or sending template name only (in case the template is already stored in marking machine's memory),
- assigning values to variables, which are contained in the template sent,
- re-asking the marking machine about the status (whether it is ready for marking),
- starting the marking – marking a string of a fixed format (template) on the mechanical product,
- monitoring progress (receiving subsequent reports from the marking machine, until the marking is completed, or, in case of a trouble, receiving a report on an error).

4.2. Communication with the database

Another requirement is to read the data of the current order from a database installed on a dedicated remote server in the company's computer network, into which the computer with the marking application is connected. Order data can be stored in a relational database table (Table 1).

Table 1. The structure of database table
[source: own development]

ID	VAL	STRING	TEMPL	FINISH
1	0;1;	Text0;Text1;	TEMPL_1	True
2	3;4;	Text3;Text4;	TEMPL_2	False
3	0;2;	Text0;Text2;	TEMPL_3	False

The table row corresponds to the data of the marking order. The example table contains the following fields: ID – row identifier, VAL – identifiers of template variables separated by a semicolon (variables with this name must be previously defined in the marking machine itself and inserted into the template code), STRING – template variable values separated by a semicolon, TEMPL – full template name defined in the marking machine, FINISH – stores the confirmation of the end of the marking (True – completed, False – not finished). To establish the table on the database server and generate database queries, like data retrieving and data saving, the SQL programming language is used. In the case of the discussed table quite simple SQL statements are applied as it is presented on Fig. 2. After the marking process is completed, the application must make a final record in the database of the result of the marking process so that the next order can be read (Fig. 3). The final save in the exemplary database is performed in the FINISH field. If there are more orders to be executed in the table, the application should inform the operator about the number of orders in the queue and allow the operator to display a list of orders that have not yet been executed, so that, if necessary, the operator can set the correct order as the current order or remove an erroneous or invalid order from the queue.

```
-- creation of Orders table; [ID] field is the primary key
CREATE TABLE [dbo].[Orders](
        [ID] [int] NOT NULL,
        [VAL] [nvarchar](50) NULL,
        [STRING] [nvarchar](50) NULL,
        [TEMPL] [nvarchar](50) NULL,
        [FINISH] [bit] NULL,
 CONSTRAINT [PK_Orders] PRIMARY KEY CLUSTERED
(
        [ID] ASC
)WITH (PAD_INDEX = OFF, STATISTICS_NORECOMPUTE = OFF,
IGNORE_DUP_KEY = OFF, ALLOW_ROW_LOCKS = ON, ALLOW_PAGE_LOCKS =
ON) ON [PRIMARY]
) ON [PRIMARY]

-- data retrieving from Orders table
select * from Orders where FINISH = 'False';

-- data saving in the Orders table
update Orders set FINISH = 'True';
```

Fig. 2. Database queries to create table, read and store data
[source: own development]

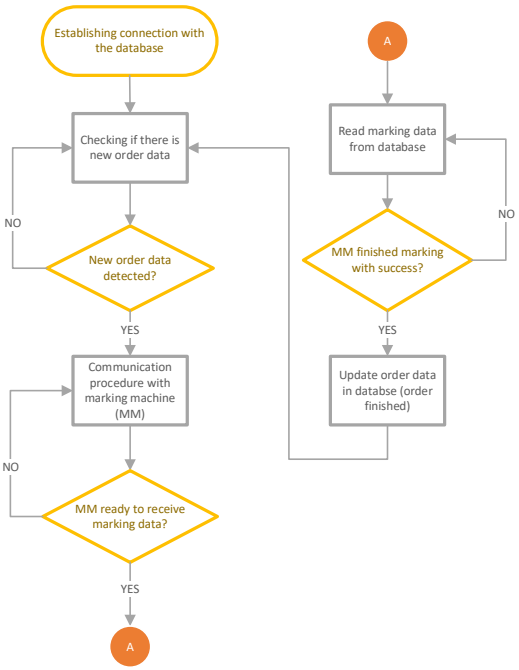

Fig. 3. Procedure of communication with database
[source: own development]

4.3. Reading data from a file

The process of transferring data for marking is based in this case on the automatic generation of a data file by the quality control measuring device. Then the computer application should be able to intercept such a file and read from it the data necessary for product identification and marking. It should also allow the wrong data packets to be removed from the marking queue, which should automatically delete the associated file. In case of reading the data to be marked from the file, the application should generate a marking report containing information on when and what data was applied to the product, what name the measurement file had and what name it was possibly changed to during the archiving process.

4.4. Procedures in case of problems

In case of problems, the operator at the assembly station of mechanical products should be able to interrupt the marking process, as well as to "acknowledge" (confirm, accept) errors signaled by the marking machine, without the need to restart the application and the marking machine itself. Therefore, there is a requirement for the following additional functions, activated by the user with physical or virtual (software) keys:

- marking interrupt function (funcBREAK) – If the parking machine is in the process of marking, one shall be able to interrupt this process at any time by sending an interrupt command to the marking machine,
- function of acknowledging errors of the marking machine (funcACCEPT) – if the machine shows an error during marking and awaits confirmation of receipt of the error, the error can be confirmed with this function,
- marking resume function (funcCONTINUE) – when the application in the test mode is set to only one marking cycle, or the operator has acknowledged the errors of the marking machine, it is possible to resume a next marking cycle with this function,
- counting the number of errors (funcCOUNT) – if the number of error messages reported by the marking machine is greater than the defined maximum value (made with application configuration interface), the user can use one of the previously discussed functions.

It is important to implement procedures in the application that allow it to return to normal operation without the need to restart the application or restart the computer itself:

- in case of an error reported by the marking machine, the operator should use the funcACCEPT function, and then, after removing the cause of the error, should use the funcCONTINUE function,
- the user interrupts the marking process in the order in which the function is used: first usage of the funcBREAK function, and then, after removing the cause of the error, the funcCONTINUE function,
- the sequence of error acknowledgments and the subsequent resumption of the marking process can be automated by inserting appropriate options in the application configuration user interface, which, when selected, automatically activate the basic problem solving functions.

4.5. Communication with other devices

If the marking data is to be obtained from an external device and provided on the user's interface, the application should provide such a possibility, e.g. communication with a torque screwdriver (to retrieve the results of twisting (torque, angle)) or a leak tester (to receive the test result, e.g. the valve opening pressure value)). In such a case, it is required to save additionally the entire marking text with data obtained from the devices, as well as separately the data obtained from these devices, in the form of a predefined production report, in a database or a in a file,

4.6. Configuring of the application

The marking application should allow the authorized user to configure, in addition to the parameters of communication with devices (i.a. the marking machine), also various access paths (to files, to the database) also in terms of the following main options to choose:

- marking machine communication testing mode – shall allow to test the communication with the marking machine by sending predefined test data, without requiring a database connection or access to input files,
- automatic acceptance of errors – results in acknowledgment of the error reported by the marking machine in automatic way,
- repetition of the marking cycle after an error – allows for automatic resumption of the next marking cycle in case of a positive response from the marking machine to the received error acceptance command,
- marking simulation – causes the marking machine to work in the marking simulation mode (without need for physical marking) for the purpose of testing the data exchange process only,
- restart – allows to reconnect to the marking machine after the marking is complete in case the marking machine closes itself the communication session.

5. Case studies

One of case studies for an application of IT support, built based on the requirements discussed, can be a manufacturing company which engraves serial numbers on metal parts. Employee has to enter data manually and configure engraving device according to type of product. The company wants to automate the process to release the employee from this part of job, which can cause failures in case the employee makes a mistake. The company does not want to buy an extensive, multi-functional software from the market. After implementation, instead of manually entering data, the applied software fetches engraving orders from an SQL database together with other configuration parameters, automatically generates text strings and sends them to the engraving machine without human intervention. It communicates with the engraving device to have the full control over marking preparation process. It confirms the finish of engraving with a feedback update query directly in the database. The system informs the employee in case of problems (for example unknown configuration parameters in the database) and new engraving order.

Another case study can be a manufacturing company of a discrete components. The company engraves a text string on that components. Essential part of data for engraving is to be retrieved from a measurement device. The formatted data has to be sent to engraving machine. The company wants to automate the process, but does not want to pay for a ready market software. The company is interested in dedicated software for this case and handling this one model of engraving machine only. After implementation, the applied software waits for measurement files generated by the measurement device in a chosen folder. Once it detects them, it reads them and prepares a string to send to engraving machine. It builds a list of engraving jobs, which is to be handled by the employee. If the employee does not do any action, the system sends the first job from the list to the engraving machine, communicates with it and, after finish of the engraving process, it removes the job from the list, prepares a report file and make a copy of the measurement file.

6. Marking software on the market

On the market there is offered already professional complex software supporting product marking from design to application on product. One example is Gravostyle, which is a professional engraving and cutting software developed by Gravotech. It is designed for rotary, laser, and hybrid engraving machines. It provides a wide range of CAD/CAM functions tailored for professional engravers. Another example is EngraveLab, which is a professional engraving software developed by CADlink Technology Corp., widely used for trophy engraving, signage, industrial marking, and personalization, tailored for both laser and rotary engraving systems. Both packages offer necessary functionality:

- design and import – enable creation intricate designs, manage text, and process images directly within the software,
- machine control – work with laser, rotary, dot peen and scribing engraving machines,
- variable data engraving and database integration, making it suitable for automated workflows,
- auto-start engraving based on database updates – when new data is added to the database, the software can automatically trigger engraving jobs,
- remote job control – engraving jobs can be queued and processed remotely using a networked database system.

There are also less equipped IT systems like i.e. Lightburn, which does not have built-in database connectivity features like SQL or external database integration, however, one can manage and store settings, such as material libraries and cut settings, which function like a simple internal database.

The second case study from the chapter 5 shows a specific case, which needs individual treatment. The commercial complex marking software offered on the market requires users to adapt their entrance data. Entry data files have to be adapted – formatted and ordered as result of prior search, analyses and mathematical operations, for example to find an average value. Other issue is a timing – once an entry file is ready, the user has to point at it and manually start fetching data. If there is no file yet, the user has to wait for it and in this way is engaged by the system longer that it would be necessary. Either way, not all cases will be handled with such systems and sooner or later IT support will be needed to develop an IT module to integrate input with output within a given special case.

7. Summary and conclusions

This article describes the requirements for information systems aimed at supporting the automated marking of mechanical products in assembly lines. The described requirements for the application are primarily related to reading input data, automatic recording of production data, product marking, which contains the recorded data, as well as handling procedures so that in case of a problem, normal operation can be resumed. The workplace operator is

relieved then of the activity of data recording and programming of the marking machine by entering data for marking, as well as assigning it an executive program. From the point of view that on the market there are already some mature complex and complete IT systems supporting automated product marking, the requirements presented in the paper rather regard IT integrators in smaller companies. Such companies do not see much sense in investing in expensive professional software, have limited budget, and want rather to program communication itself, based on documentation delivered by a producer of the marking device. So this paper could be a valuable set of ideas and possible requirements for such dedicated integration jobs.

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