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INDUSTRIAL ASSEMBLY LINE OPERATION

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ABSTRACT

The idea of this paper is to present basic components of a flexible assembly system (FAS), discuss it characteristics, classify the systems and describe an application. This equipment offers professional training according to the industrial reality, simulating a real assembly process and including different technologies from Industry 4.0. The FAS consists of an automated flexible assembly cell with five different stages: assembly, handling, quality inspection, transfer and warehouse. It is the ideal answer to research and training in industrial automation. The main advantage is that it has fully modularity in keeping with industrial reality. The technologies included in its different assembly modules, as well as the assembly process with several variants, allow the user to develop the professional skills required by advanced automation. In this work the conventional control approach is presented with programmable logic controllers (PLC) and SCADA level.

1. INTRODUCTION

Smart Manufacturing is considered as a new paradigm that make work smarter and more connected, bringing speed and flexibility through the introduction of digital innovation [1]. Today, digital innovation is closely linked to the "sustainability" of companies. Digital innovation and sustainability are two inseparable principles which are based on the concept of circular economy. Digital innovation enables circular economy model promoting the use of solutions like digital platforms, smart devices, artificial intelligence that help to optimize resources.

The main part of Smart Manufacturing are flexible assembly systems [2]. A flexible assembly system is a fully integrated production system consisting of computer numerically controlled assembly stations, connected by an automated material handling system, all under the control of a central computer. The FAS is capable of simultaneously assemble a variety of product types in small to medium-sized batches and at high rate comparable to that of conventional transfer lines designed for high volume/low variety manufacture [3].

The aim of this paper is to present basic hardware components of a flexible assembly system and discuss it characteristics, classify the systems and describe some real applications. The FAS-200 system is the ideal answer to research and training in industrial automation. It is fully modular and flexible equipment and in keeping with industrial reality [7], [8].

2. AUTOMATED INDUSTRIAL SYSTEMS

The fully automated manufacturing environment has been the ultimate goal of industrial companies that for a few decades already [4]. The idea was first put forward with the rise of the Computer Integrated Manufacturing (CIM) [5] in the early 1980s. Nowadays sophisticated communication technologies, big data analytics, Industry 4.0 technologies and integrated electronic components and modules enable automation possibilities and the realization of new business models [6]. However, only a small number of companies still aims for a completely deserted and fully automated.

Today, the workers and employees are seen as flexible and agile factory assets who should be supported in the best way possible. With the combination of human flexibility and experience on the one hand and the potential of process and factory automation on the other hand, major breakthroughs in the manufacturing environment are achievable. An effective human-machine collaboration enables companies to establish a production line or factory site suited for complex and/or highly integrated products that will continue to be profitable in future. Even though today's machines run automated processes, these are typically based on linear control systems. The concept of the automated factory transfers the already successfully applied use cases of automated basic processing steps at the single machine level (e.g. assembly of particular components) to an in-house and even to a global industry level. Automated factories conduct major steps from material preparation via production to testing in an automated manner. The demand-driven self-operation of

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production allows parallel instead of linear production workflows within one factory and along the entire supply chain, e.g. products are being tested virtually while materials are being prepared for its production.

Only the automated factory with an optimal supported flexible workforce can lead the industry to an efficient mass-customization of goods. To achieve these goals, FAS is pivotal as shown in the next section.

3. ASSEMBLY SYSTEM DESCRIPTION

It is described a training equipment in mechatronics connected with Industry 4.0 technologies. This is a flexible assembly system FAS – 200, installed at laboratory of Intelligent Automation Manufacturing Systems in the new Centre of Competence "Smart Mechatronic, Eco- and Energy Saving Systems and Technologies ".

FAS 200 [7] is comprised of different stations, each performing a part of assembly process. The flexible assembly system has been specially conceived for persons to acquire professional capabilities in connection with the Occupational Groupings of Electricity/ Electronics and Maintenance, such as: -Installation, Electromechanical Maintenance and Line Transport; - Industrial Equipment Maintenance; - Automatic Control and Regulation Systems. It enables the development of various skills associated with pneumatic, electropneumatic, electrical, robotic and handling automatisms, programming and PLC technologies, industrial communications, supervision, quality control and fault diagnosis and repair. It also allows the study of a wide range of sensor types: - magnetic detectors; inductive detectors; optical fiber sensors; photoelectric detectors; capacitive detectors; pressure and vacuum switches; linear encoders. The system includes a flexible automation cell which carries out an assembly process involving a number of predetermined parts with different possibilities. The parts are transported consequently to the connected modules by an automated linear transfer line with corresponding stoppers and precision lifters-positioners. Parts are mounted on pallets. The process modules function either independently of the transport system, in single or couple modes, or integrated into it, in cell mode. The modules are located in a side of the linear transfer, and may be withdrawn for re-positioning in a different order (the repositioning of different modules of the system can mean repositioning of stoppers, lifters-positioners and reprogramming of the controllers of the system), moved for future extensions or work in completely independent, in a single mode, or with its complementary module in a couple mode (requiring reprogramming of the control). Each station has its own electrical panel, where the wiring system and PLC are fully visible, while new elements may be fitted to the panel if it is necessary. The users may design and build their own projects with different PLCs and subsequently integrate them in the station. They can develop a further series of skills envisaged in the training cycles for those persons who form the target group for the cell. The front of each station incorporates the start, stop, step-by step/continuous cycle and reset pushbuttons. In addition, the control pushbuttons incorporate a main switch on/off and emergency pushbuttons for emergency stops. The system is modular and may be extended, which allowed a future incorporation of other process modules according to the user needs. The modules are mounted on aluminum sections, which are tables with a large surface area and multiple slots. This allow all types of extension and modification. The assembly process performed is as follows:

Process A: Feed body or base to which the other parts are assembled and verification of its orientation.

Process B: Pick and place bearing and measurement of its height.

Process C: Press bearing in hydraulically.

Process D: Pick and place shaft and verification of its orientation and material.

Process E: Pick and place cover and verification of its orientation, material and color.

Process F: Fit screws.

Process G: Robot screw driving.

Process H: Quality control by artificial vision.

Process I: Unloading, storage and palletization of final assembly.

In addition to transport processes between with a linear conveyor.

Transfer and vision inspection module

The transport system, Fig. 1 is composed by long lines including five modules to facilitate the envisaged assembly process.

Fig. 1. Linear transfer module

Different layouts can be defined for future expansions. The transfer follows a rectangular path or linear path. The master PLC controls and coordinates the rest of the PLCs connected to the network and it is located in the "body feeding and checking" station. There is a longitudinal channel in one side of each module and of the linear transfer to provide the electrical power connections and the air supply connections between the different stations (and in the communication connections). The modular transfer incorporates a pallet assembly to transport parts and assemblies across the handling stations. The pallets and the transfer stoppers incorporate a binary coding system using inductive detectors, which allow the control system to identify the position of each pallet at any time.

Vision system:

The body is going to the first of two inspection positions, and a vision camera confirms the color and presence of the shaft, the height, the color and the presence of the cover and the presence of two of the four screws, Fig. 2. The system is used with monitoring purposes, based on an open-loop concept. Then it rotates to the second inspection position and the vision system confirms the presence of the remaining two screws. If the inspection results are good, the turning mechanism is returned to the pallet retained at the transfer. The vision system consists in a vision sensor with integrated camera and controller. It can be used to easily achieve simple inspections and measurements.

Fig. 2. Vision system

Feeding and transferring module

This feeding module feeds the bearing which is going to be placed inside the housing formed in the body by the next module. Also, this module transfers, Fig. 3 the bearing to the measurement position located on the next module, where the height is measured to differentiate between the two sizes of bearing.

The feeding operation begins when the pallet is positioned opposite to the next module. The pallet is held in a determined location by a stopper and a positioner-lifter on the linear transfer. Confirmation that the pallet is in the correct position is provided by a microswitch which sends the appropriate signal to the PLC of the next module which in turn sends the signal “start cycle” to the PLC of feeding module.

Fig. 3. Manipulators of the feeding module

The feeding module, like the others, may be divided into a series of manipulators. Each sub-module has been made as a set of components which performs a specific operation within the whole assembling process carried out at the module. The feeder which supplies the bearing is of the gravity feed type. The bearings are stored in a column. The next bearing is extracted at the moment the cycle starts, so when the bottom bearing is removed, the next falls into the place under the its own weight and that of the ones above it. In this case, a sensor in the form of a microswitch checks for a bearing presence. This allows the PLC to verify that the bearing really has been extracted after the feeding procedure. This way it is possible to determine when the bearings loaded in the feeder have run out. A manipulator moves the bearing from the feeding position to the place where the height measuring operation in the next module will be performed. The manipulator uses a rack and pinion type rotary actuator which describes an angle of 180°. To the rotary actuator it is attached an arm, which moves a two-finger parallel-opening gripper which grips the inner part of the bearing. This arm houses a mechanism consisting of a toothed belt and two pinions. The purpose is to keep the gripper orientation throughout the turning movement, so that it can reach the measuring point in horizontal position.

Measuring and transferring module

The measuring module is complementary to the previous one. It is measured in this module the height to differentiate between the two sizes of bearings, Fig. 4. This module rejects the bearing or places it inside the housing of the body on the pallet, depending of the signal “tall bearing” or “short bearing”. The confirmation of the bearing has got the correct height is got by a linear potentiometer like a measurer turning on an internal flag of the PLC, signal “tall bearing” or “short bearing”.

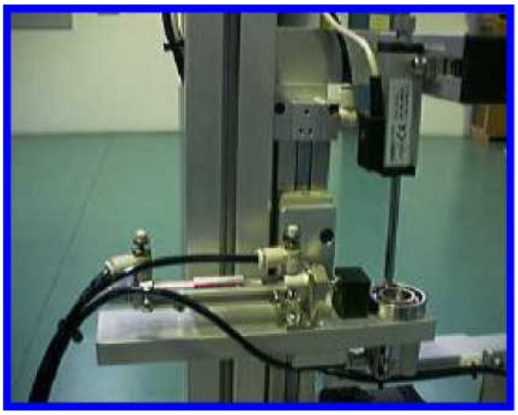

Fig. 4. Measuring manipulator

When the pallet is positioned opposite the module this operation begins. The pallet is held in a determined location by a stopper and a positioner-lifter on the linear transfer system. When the PLC of the third module sends the signal “end cycle” to the PLC of this fourth module. The task of placing the bearing is performed on the pallet brought by the belt conveyor and carrying the body fed and assembled by the previous modules. The bearing fitting operation requires the pallet carrying the body to be precisely situated in a predetermined place. To achieve this precision, once the pallet has been retained by a stopper, it is lifted by a pneumatic cylinder and centered at the same time by four pins which fit inside housings formed for this purpose in the bottom of the pallet.

The measuring module, like the others, could be divided into a series of manipulators. Each sub-module has been made by considering it as a set of components which performs a specific operation within the whole process carried out at the main module.

• Measurement of height:

The module allows the possibility of feeding bearings of different heights, because a measuring manipulator is included to measure the height and to select them. The bearing is placed on a platform, with a centering device operated by a pneumatic cylinder which locates it at a very precise position. That is needed to perform the correct measurement of the height. This platform is lifted by a rod less pneumatic cylinder. This way the bearing contacts a touch sensor and gives the height reading. The touch sensor consists of a linear potentiometer with an output, connected with an analogue module, included in the PLC. The lifter returns to its original position after measurement. After that, a cylinder pushes the bearing towards a ramp, in case the height does not correspond to the selected one. The final operation is performed by a manipulator. It comprises a rotary-linear system, with an arm to which a two-finger gripper has been fitted. After picking up the bearing, the arm goes up, turns through 180° and then goes down again to insert the bearing in the housing of the body.

Cover classification module

The fourth of the components to be assembled in the system FAS200 is a cover which is fitted into a housing formed on the body for this purpose, Fig. 5. The cover serves to retain the turning mechanism shaft mounted at the previous modules. While the preceding modules saw the introduction of a variant in the form of different materials for the shaft, this module increases the number of variants by offering the choice of three different materials for the cover: aluminum, white nylon and black nylon, in addition to a choice of two different cover heights, giving a total of six possible combinations for this particular assembly task. The need for appropriate checks to determine which type of cover is to be assembled at each module cycle means that this module is one of the most complex in terms of the operations to be carried out. It is also essential that the module control coordinates part selection operations in accordance with the commands supplied by the master responsible for production management in the FAS-200. This classification module feeds the cover which is the closure cap for the turning mechanism, and verifies its material, color and height.

Fig. 5. Manipulators of the cover classification module

Then, the next module rejects the cover or places it onside the housing of the body on the pallet, depending of the signals “metal cover”, “plastic cover”, “black cover”, “white cover”, “tall cover” and “short cover”. The confirmation of the cover is the correct one (material, color and height) is got by some sensors (an inductive detector, a photoelectric detector and a pneumatic cylinder with stroke reading) turning on some internal flags of the PLC, the previously mentioned signals. This operation begins when the pallet is positioned opposite the module, held in a determined location by a stopper on the linear transfer system. Confirmation that the pallet is in the correct position is provided by a microswitch which sends the appropriate signal to the PLC of the module which sends the signal “start cycle” to the PLC of this module. The feeding module, like the others, may be divided into a series of manipulators. Each sub-module has been made by considering it as a set of components which performs a specific operation within the whole assembling process carried out at the module.

• Index plate:

This element is used as a system of alternating rotary movement, in the sense that each turning movement moves the plate round by a number of degrees equal to the circumference divided by the number of defined positions. In this case, it is a plate of 8 different positions. To achieve this effect, the system incorporates a pneumatic pusher cylinder with back and forth movement giving the required angular advance. There are a further two stop cylinders which function alternately, one moving which holds the plate during the turn, and another fixed cylinder which locks the plate in position when movement has ceased. In this way, the plate is held firmly and the pusher cylinder can return to its initial position to await a new cycle.

• Cover feeder:

The covers stored in a gravity type feeder are deposited on the first plate position via a step-by-step feed system involving two pneumatic grippers. These grippers are in a permanent counterpoise position, so that while the lower one releases the next cover from the feeder, the upper one holds the rest in place. A presence sensor in the form of a fiber optic detector allows the PLC to verify that there is really at least a cover in the feeder to continue the feeding procedure. This makes it possible to determine if the covers loaded in the feeder have run out.

• Cover measuring position:

The fact that covers of two different heights may be assembled necessitates a height measuring device. Owing to the teaching and training objective for which the cell has been designed, various solutions have been used to perform similar operations, so that while components such as pneumatic cylinders with correct height detectors or analogue output touch probes have been employed at other modules, this particular module uses a digital transducer which provides a pulse output, as it is a linear encoder. The component used consists of a pneumatic cylinder which moves the probe until it touches the cover. An integral linear encoder in the cylinder sends pulses which are counted by a quick counter input at the PLC, making it possible to determine the distance the cylinder advances until it contacts the cover. This information allows direct determination of the height of the cover.

• Material detection position:

As described above, this module offers the possibility of working with aluminum, white nylon and black nylon respectively. To differentiate these types, the next index plate position is fitted with an inductive detector and a photoelectric detector which supply the necessary signals to the PLC.

Detection of the metal covers necessitates the use of a inductive sensor, which supplies a signal when the part detected is made of metal. The final cover differentiation process is that between black and white nylon, and for this purpose a photoelectric cell as in figure is fitted. This component only detects white-colored nylon covers.

Cover rejecting and transferring module

This module, Fig. 6 is complementary to previous one. This module rejects the cover or places it onside the housing of the body on the pallet, depending of the signal about the cover material from the PLC of the previous module. This operation begins when the pallet is positioned opposite the module, held in a determined location by a stopper on the linear transfer, and when the PLC of the module sends the signal "end cycle" to the PLC of this module. The task of placing the cover is performed on the pallet brought by the belt conveyor and carrying the body-bearing-shaft assembly fed and assembled by the previous modules. The cover fitting operation requires the pallet is stopped and retained by a stopper.

The tenth module, like the others, may be divided into a series of manipulators. Each sub-division has been made by considering it as a set of components which performs a specific operation within the whole process carried out at the module.

• Rejection of incorrect cover:

If the cover reaches the last-but-one index plate position (on the previous module), and the various material or height sensors have indicated that it is not of the material or height indicated by the main controller in charge of production of the system.

FAS 200, then it must be rejected. This operation is implemented at this module by a two-cartesian axes manipulator, which picks the cover off the index plate and deposits it on a removal ramp if the corresponding signal is received.

Fig. 6. Cover rejecting and transferring module

The manipulator comprises two pneumatic parallel rod cylinders, at the end of which is a suction plate with three vacuum-holding cups.

• Cover insertion:

Cover insertion, carried out from the last of the index plate position (on the previous module), is performed by a rotary-linear type manipulator. This rotary- linear cylinder makes it possible for a single component to pick up the cover, take it to the unloading point and insert it. The cylinder offers the possibility of independently commanding rod in stroking and out stroking as well as turns to left or right. It is this cylinder which turns an arm fitted with a parallel opening gripper used to holds the cover throughout the movement, which is lifted and turned towards the unloading point by a rotary- linear pneumatic actuator.

Warehouse module

Once the final assembly is completed, the warehouse module has to be removed from the transport system. This storage module, Fig. 7 uses a system based on two coordinate axes, so that the bodies (with bearings, shafts, covers and screws) picked off the conveyor belt may be allocated at any point on the surface of the module. The storage module, like the others, may be divided into a series of manipulators. Each sub-division has been made by considering it as a set of components which performs a specific operation within the whole process carried out at the module.

• Vertical axis:

The system of holding the components of turning mechanism consists of parallel rod cylinder equipped with a plate including four suction cups which to hold the assembly until it is positioned at its storage point.

• Positioning axes:

The first operation consists of placing the vertical axis mentioned above over a fixed pick-up point over the place where the pallet is stopped.

Fig. 7. Manipulators of the warehouse module

This operation is carried out by two shafts: one of them is a pneumatic actuator and the other one is a positioning shaft driven by servomotor with absolute encoder to provide instantaneous reading of motor rotation, achieving the precise regulation of position and speed via their corresponding driver which set up a closed loop position regulation system. This involves encoder feedback and the position setpoint required at any particular moment supplied by the PLC controlling the module.

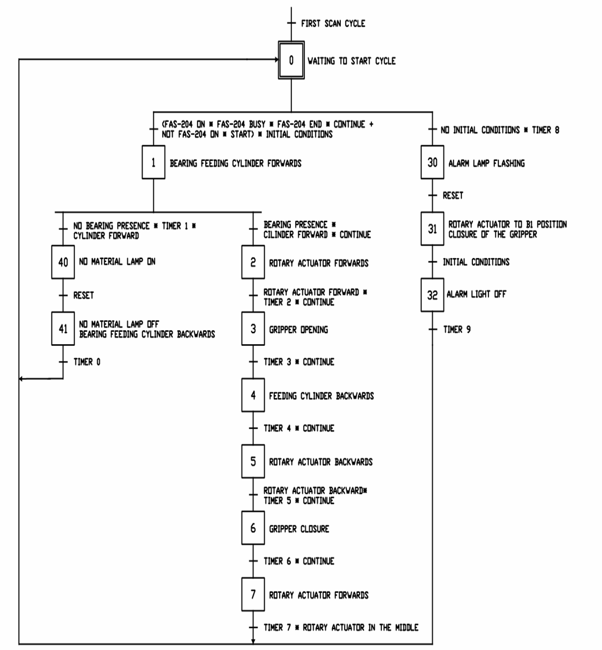

Fig. 8. Program for the feeding module

4. ASSEMBLI LINE OPERATION

During operation with the flexible assembling system they are used functional PLCs software programs implemented like structural function codes, evident from Fig. 8. It is used KEPServer for devices communication and SCADA system, Fig. 9. All stations are presented as clients: FAS 203, FAS 204, FAS 209, FAS 210, FAS 216. Next figure presents the device parameters for the first station with PLC S7-1200 and defined IP address. The Input and Output assignment is presented on Fig. 11. These are addresses used in user program for system functionality.

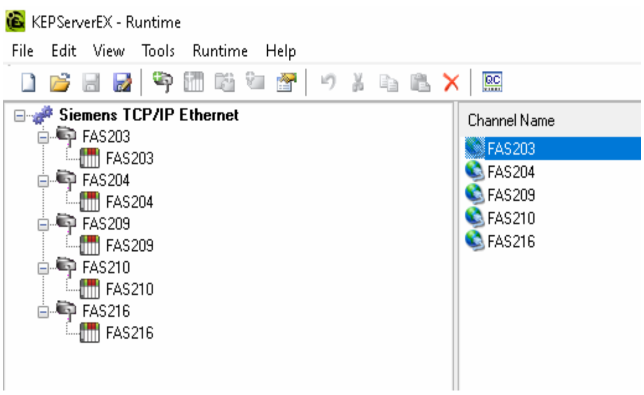

Fig. 9. Setting the modules as clients in KEPServer

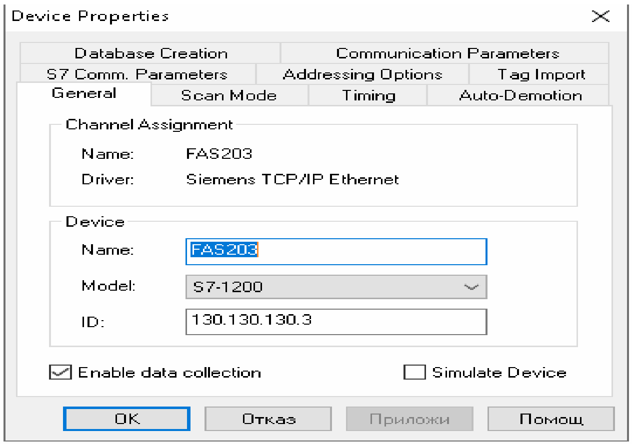

Fig. 10. The FAS 203 station parameters

Tag Name	Address	Data Type	Scan Rate	Scaling	Description
FAS203_in0	MW300	Word	100	None	Info from the PLC
FAS203_in1	MW302	Word	100	None	Info from the PLC
FAS203_out	MW310	Word	100	None	Info to the PLC

Fig. 11. I/O assignment

Fig. 12. SCADA main screen

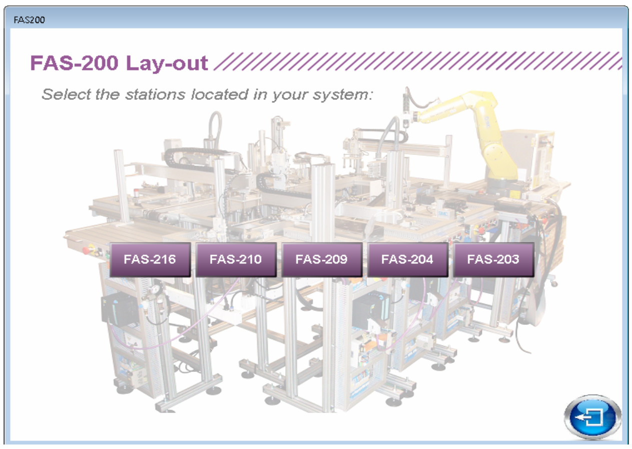

Fig. 13. All modules in the project

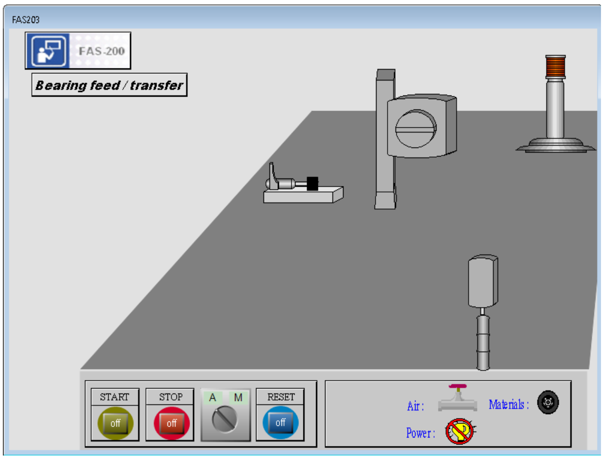

Fig. 14. Screen for monitoring and control of the first module, FAS203

The prepared SCADA project with Omron software CX-Supervisor is presented. On Fig. 12 the main screen is given and operating can be started. The monitoring and control for the first module is presented on the Fig. 14. It is for feeding stage of the manufacturing system. The quality control, sorting and rejection are shown on Fig. 15. Respect to the user definition and selected options this module operates. The nest station includes different covers for parts and can be predefined and selected from three types. Fig. 16 general screen for cover classification and table with positioned covers.

The assembly stage is presented with screen on Fig. 17. At this step can be make rejection as well as it is possible in module at FAS 204.

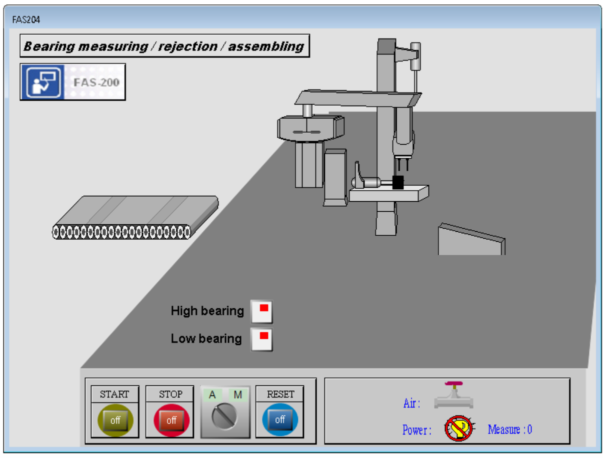

Fig. 15. Screen for quality control, FAS 204

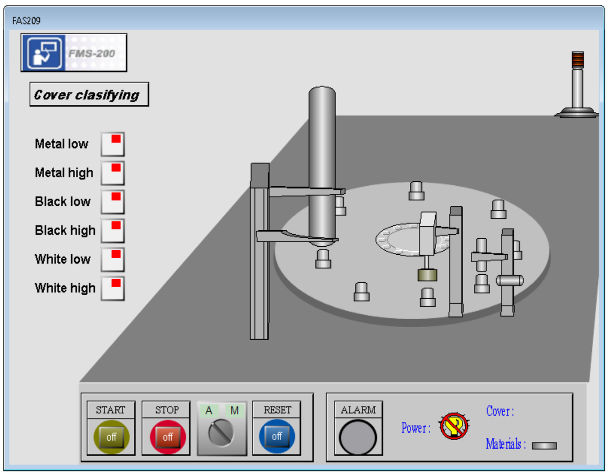

Fig. 16. Screen for covering, FAS 209

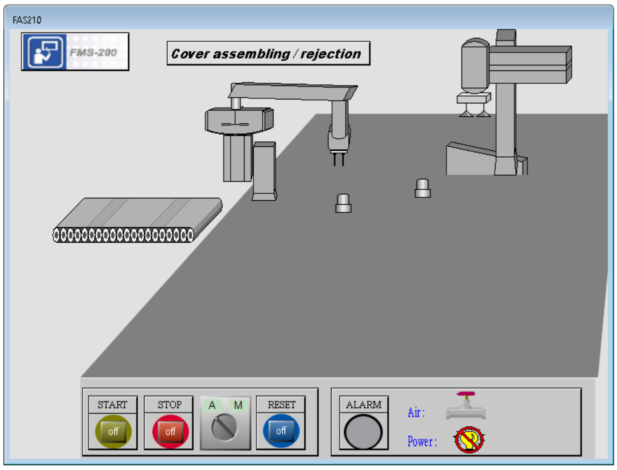

Fig. 17. Screen for assembling stage, FAS 210

The last station is focused on placement of the ready production, Fig. 18.

The results obtained during operation of FAS 200 show a correct function of the system and software implementation. For this purpose, it is used a SCADA operational system for configuration, communication and monitoring of all system elements.

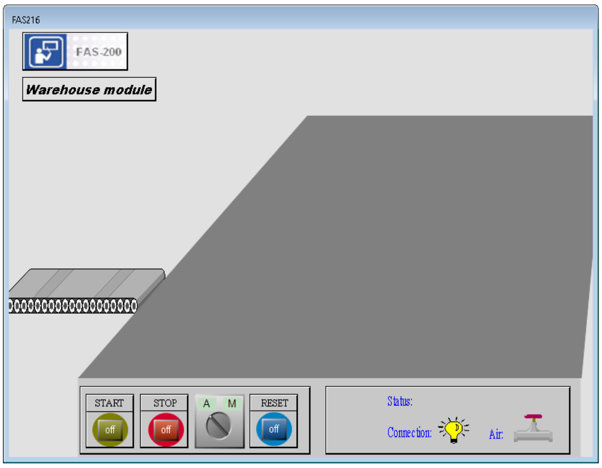

Fig. 18. Screen for warehouse storage, FAS 216

5. CONCLUSION

In recent years the manufacturers have invested most to the beginning and of the production process. To the designing stage by introducing of FAS systems and to production stage by modernization of production. FAS systems became standard by majority of manufactures, therefore if they still want to increase competitiveness, they have to increase efficiency, productivity and quality of production. This is main reason that technologically advanced countries focus on preparation and realization of modern manufacturing systems, mainly new.

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REFERENCES

[1] Liang S., Rajora M., Intelligent Manufacturing Systems: A Review, International Journal of Mechanical Engineering and

Robotics Research 7 (3) (2018) [Online]. Available: https://www.researchgate.net/publication/ 324598110

[2] Elmaraghy H., Flexible and reconfigurable manufacturing systems paradigms, International Journal of Flexible Manufacturing Systems 17 (4) (2005) 261-276

[3] Asadi N., Flexibility in Assembly Systems using Product Design, Ph.D. dissertation, Mälardalen University Press Dissertations., Printed by E-Print AB, Stockholm, Sweden (2017)

[4] Ahmadi A., Cherifi C., Cheutet V., Ouzrout Y., Recent Advancements in Smart Manufacturing Technology for Modern Industrial Revolution: A Survey, Journal of Engineering and Information Science Studies (2020) p.21, hal-03054284

[5] Groover M.P., Automation, Production Systems, and Computer-Integrated Manufacturing, Harlow, Pearson Education (2014)

[6] Cohen Y. and col., Assembly system configuration through Industry 4.0 principles: the expected change in the actual paradigms, IFAC Papers OnLine 50 (1) (2017) 14958–14963

[7] SMC Networks. FAS-200 User Manual (2020) p.97

[8] https://www.smctraining.com/ SMC International Training.