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LOW COST INTELLIGENT AUTOMATION IN MANUFACTURING

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Abstract: To be competitive SMEs with small batch production or tool- and mould making are forced to use numerical controlled manufacturing processes and computer based shop floor control. But the technological support for these enterprises should be shop floor oriented to foster and develop human skills in flat hierarchies avoiding unnecessary dividing of work. With shop floor oriented production support human skills and automation create synergetic effects. The mastery of the manufacturing process is in the hands and brains of skilled workers. Automation gives the necessary support to execute tasks and rationalize decisions. This represents a way of low cost automation. To run the manufacturing process effectively is not only a question of technology though an essential one. Together with an adequate work-organization wherein human skills can be empowering themselves it establishes the frame for a competitive manufacturing in SMEs. This contribution deals with shop floor oriented technologies for manufacturing. *Copyright © 2002 IFAC*

Keywords: machine tool controls, shop-floor oriented technologies, maintenance support

1. INTRODUCTION

A recent study by G. Lay (2001) reveals that booming revenues for automation technology vendors hide the fact that belief in automation in the German investment goods industry is giving way to sober realism. More than a third of 1000 reviewed enterprises had already reduced their degree of production automation or plan to do so. The most important reason: The insufficient flexibility of highly automated systems.

The combination of losses resulting from conversion, idle time and high technical maintenance costs quickly negated the expected economic benefits. Today at many locations highly automated production facilities are making way for systems with significantly lower degrees of automation. Exaggerated automation was found just as often at small enterprises as it was at larger companies.

Highly automated material flow systems in assembly and highly automated processing machines are partly seen as poor investments. Two thirds of unsatisfied companies indicated that today's shrinking series sizes can no longer be handled economically with these systems. Inadequate flexibility in capacities follows as the second most popular reason for dissatisfaction. Companies with innovative product ranges face special difficulties. They have considerable problems for assembly stations and material flows in production. It appears that short innovation cycles define the limits of economical automation.

Within the last years so called shop floor oriented technologies got developed and achieved success at least but not only in small and medium sized enterprises (SMEs). They are focused to agile manufacturing, that means to use an intelligent automation combined with human skills and experiences at the workshop.

Some criteria of these technologies are to mention:

1) with respect to the man-machine interfaces:
   - flexible machine tools with easy access to the working area
   - manual and numerical controllable machine tools
   - graphical-interactive programmable NC-controls
   - multimedia supported interpretation of the machine diagnosis respecting maintenance through operators,
2) with respect to machine-machine interfaces:
   - PC´s at the shop floor with NC-programming software for different controls but with identical structures and user surfaces as these machine tool controls and with program transfer between machine controls and PC in both directions,
3) with respect to shop floor planning

- electronic planning boards or shop floor control systems usable by skilled workers for making decisions with respect to scheduling tasks, shorten the through-put time and solving problems caused by still stand of machines, missing tools or jigs and fixtures, material or personnel,

4) with respect to product and process quality
   - devices for in-process measuring
   - for all skilled workers usable statistical process control and statistical experiments.

Group- or teamwork supporting technology is an additional criteria. This means the technology should be usable in a sporadic manner by all skilled workers depending on their tasks just now.

2. NUMERICAL CONTROLS FOR MACHINE TOOLS

Investing in a new or at least better technology is connected to decisions for machines with enhanced productivity of the manufacturing process and also to producing a better quality of the products. There are to points to consider:
investing in new machines or
retrofitting of existing machines.
For machine tools or manufacturing cells or systems it is not always necessary to replace them

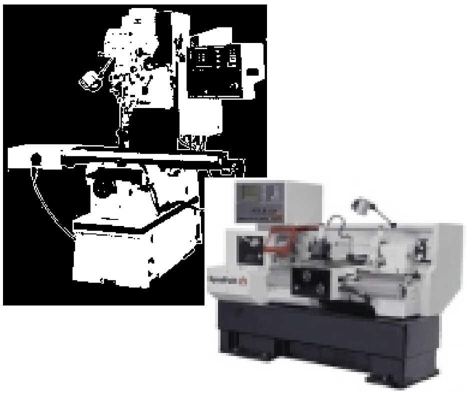

Fig. 1. Machine tools with job-shop controls

completely. In many enterprises one can find conventional machines in a very good state but meanwhile not suitable to produce parts of high quality in an adequate time. Conventional machine tools like lathes or conventional mills have usually a machine bed of a good quality and stiffness. They should not be thrown on the scrap-heap. These machines could be equipped at least with linear rules and digital read-outs (DRO) to improve the manufactured quality with respect to required tolerances. The next improvement could be the refitting with a numerical control (NC-program interpreter, PLC, servo-drives as actuators for each controllable axis, a measurement system as sensors), while the drive of the main spindle can be controlled using a frequency converter. Retrofitting packages are available on the market (www.giddings.com). Numerical controlled machines of the first generation sometimes only need a new control to put them to today's standards. That is called "upgrading". Sometimes it is desired to save the conventional handling of machines despite its retrofitting, i. e. moving the tables and saddles mechanical with hand wheels in addition to the numerical controlled servo drives. This facilitates the manufacturing of simple parts before using the advantages of a CNC-control to manufacture geometrical complex work pieces. Such controls of machine tools enabling the in-process switch from manual processing to a support of a numerical control is an intelligent enhancement of the productivity of the shop floor. They are suitable for manufacturing small lots or single parts, easy to handle manual and programmable with interactive graphic support at the human-machine interface. These controls are called "job-shop" - controls.

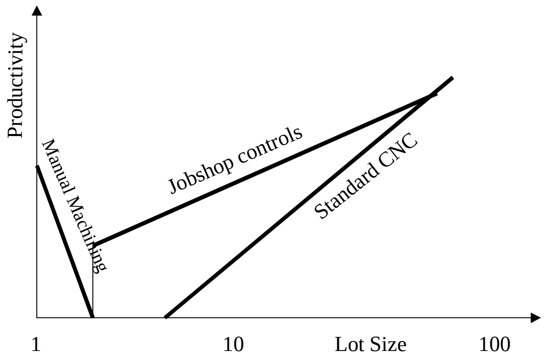

Fig. 2. Benefits in productivity with job-shop controls

The knowledge and experience of skilled workers can be challenged and a dividing of work in programming and operating to different personnel is unnecessary, saving costs while avoiding organizational effort and is more flexible. Figure 1 shows machine tools with job-shop controls and Figure 2 its productivity respective the lot size. Job-shop controls of Siemens, Hurco et al (www.ad.siemens.de/jobshop;www.autocontech.com), are using PC-operation systems like Windows NT and can therefore be integrated in an enterprise network and connected to the internet. These allows for a flexible manufacturing, because not only an easy programming at the machines but also archiving of programs and loading of programs from other places is possible. Moreover the connection to tool data management systems allows for a quick search and ordering the right tool at the workplace. These open factory systems are meant to expand the functionality of traditional numerical control (CNC) technology by leveraging the interoperability and familiarity of a PC. Incremental functionality such as ease of operation, custom interfaces, networking, and diagnostics are all tasks ideally suited for machines combining CNC and PC technologies. Careful selection of a PC-enhanced CNC can simplify use, expand functionality, reduce

maintenance, and raise productivity - and can do all this while lowering the total cost of ownership. The introduction of the PC to the shop floor has the potential and do already change the manufacturing. The CNC and PC should be integrated, not just connected. This mean that the CNC and PC are installed in the same unit, but integration is possible in remotely connected units as well because what's critical is the degree of logical integration. The CNC and PC must be able to exchange extensive amounts of data at rates consistent with the inter-workings of the CNC, and this data must also permit real-time adjustments to the machining process. This tight integration is seen often in adaptive control applications, diagnostics, and custom user interfaces. Improved operator interfaces, central tracking and analysis of statistical process control (SPC) data, and access to the machine from the internet are all common applications appearing on open systems CNCs. Figure 3 shows a machine shop solution of GE Fanuc Industrial Systems (www.gefanuc.com).
As it was concluded within the study of G. Lay (2001) mentioned in the introduction high automation of production processes could be inflexible regarding the quickly changing demands of the customers. Future factories have to be dynamically reconfigurable to quickly support customer requirements. To achieve this human skills and ingenuity at the shop floor is unavoidable and have to be assisted.
An important tool is "virtual machining". An

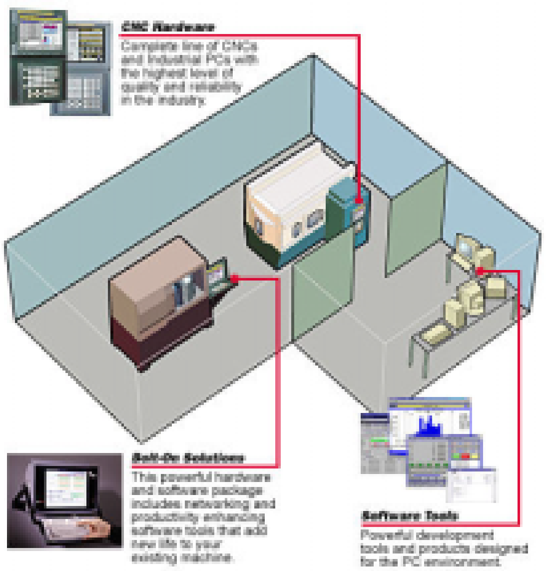

Fig. 3. Machine shop of GEFanuc

accurate simulation of a manufacturing process in a machine tool or machining center by high-end visualization got developed (www.CGTech.com) running on PCs (Figure 4). Skilled workers can use this tool to plan the complex manufacturing for optimizing in short time. Furthermore a change of the production process due to customer demands can be quickly simulated to find the optimal way. Virtual tools are available using tool management systems provided by tool makers via the internet. An accurate simulation of jigs and fixtures is also possible using data of fixture suppliers also via the internet. The workers can document the first

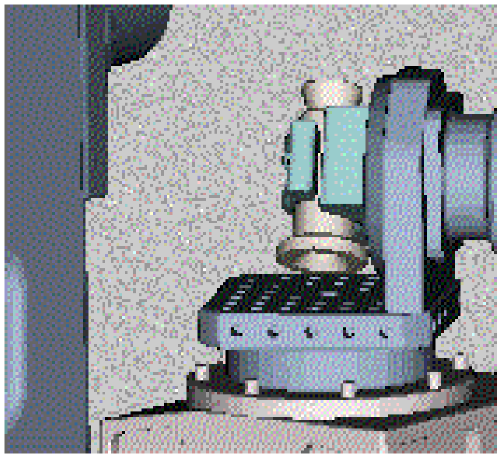
Fig. 4. Virtual machining (CGTech/Vericut)

assembly of fixtures in a machining center in a data base at a PC or the machine control, using a digital camera. This allows for saving the knowledge and experience for future use and shortens the setup time when manufacturing new parts.
A very important tool to reduce the cost of manufacturing is the Design of Experiments (DOE). This is connected with the names of Taguchi and Shainin (Bhote, 1991). Automatic Statistical Process Control (SPC) used in-process only identifies deviations from the demanded quality of the manufactured parts. But which machine parameters have to be changed is sometimes a fiddly question. DOE offers a systematic search to find the most important parameters and their interrelation. The experiments can be executed through the skilled workers at the shop floor, thereby shortening the time to an again stable manufacturing process. Figure 5 shows a graphic representation identifying the most important machine parameter.

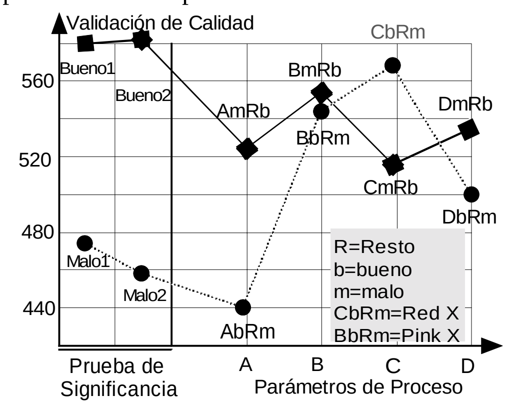

Fig. 5. Variable/Parameter search of DOE

Production to market demands requires the high availability of machines and this is last but not least a problem of maintenance.

3. MAINTENANCE

According to Morel (2001) maintenance should keep a systems facilities functioning in order to contribute to the enterprise target. Maintenance should fulfil the right CRAMP parameters (Cost, Reliability, Availability, Maintainability, and Productivity) for any automation system. Maintenance strategies and operations should be considered as a complete process aiming to maintain the production resources while inter-working with other shop-floor and business processes (automation, planning, quality, management, financial, etc) to carry out the global enterprise goal. Engineering of such a maintenance system needs a holistic approach for integrating views and evaluations, not only of the systems themselves, but also for their mutual interactions and their interactions with the environment.
Two approaches for the maintenance of an automation system can be considered:

an a posteriori approach based on an exploitation of the system data coming from experience and the knowledge practices of the real operation. It allows for decision making of maintenance strategies as a feedback in the system design phase or as an optimization on line. Again according to Morel et al one of methods most used to improve the maintenance plans for automation systems is RCM (Reliability Centered Maintenance). RCM is a procedure for determining maintenance strategies based on reliability techniques. The methodology takes into account the prime objectives of a maintenance program:

- minimize Costs.
- meet Safety and Environmental Goals.
- meet Operational Goals.

The effects of redundancy, cost of spare parts, costs for maintenance personnel, equipment aging and repair times must be taken into account along with many other parameters. The RCM process may be used to develop a living strategy with the automation system model being updated when new data is available or design changes take place.
A good source of failure information about an automation system is the experience of operators on site. Translating this information into future probability of failures can be performed with the Bayesian reliability analysis (Morel, 2001).

an a priori approach based on the knowledge to controlling system variables regularly, for (a) optimizing the intervals between repairing, (b) reducing the number and the cost of unexpected stillstands, (c) anticipating the failings of the system. Some studies on the efficiency of the management in maintenance showed that a huge part of maintenance costs results from useless or badly made repairs. For example, sometimes scheduled maintenance is blind because the equipment, which is changed, could be in a perfect operating condition. This not only increases the costs of production, but also decreases the lifetime due to the damages of equipment done by the maintenance action itself.
An implementing of condition-based and predictive maintenance substitutes scheduled maintenance to decrease expenses and to improve the global performances of the automation system. Studying the systems "degradation" to anticipate its failures offers an image of the future situation of the system.
Therefore the implementation of these processes within the framework of a predictive versus pro-active maintenance strategy involves some a priori knowledge on the system and on its components with a use of this knowledge to represent the views on the future directions of this system.

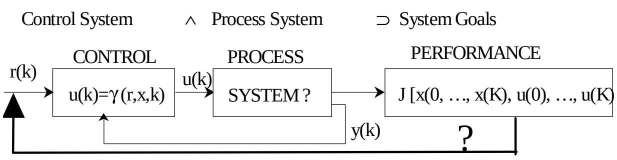

Fig. 6. A closed-loop system with system performance optimization rather than control performance optimization (Morel, 2001)

Morel et al (2001) stress the consideration of the performance of the complete system, that is interesting the owner respecting the cost, rather than the control performance only. I.e. a compromise between cost of maintenance and cost of stillstand of the automation system (Figure 6).
Due to increased demands on performance of manufacturing systems (quality, reliability and safety) spending for maintenance is likely to grow. Therefore an agility for the maintenance of the next generation of information- intensive manufacturing systems requires to broaden the mindset of the well-established system-oriented approaches in favor of more intelligent technologies and way of thinking.
After this more theoretical considerations some operational solutions of maintenance are discussed in what follows.
The concept of Total Productive Maintenance (TPM) integrates maintenance into production and therefore enlarge the tasks of the productive workers at the shop floor. To master these additional tasks the operators of manufacturing systems need a deep understanding of the structure and support for their decision making respecting active and proactive maintenance. Necessary for these tasks are well prepared interpretations of the diagnosis information. With this support and their collected experiences when operating the manufacturing system they are enabled to locate the problem and to decide if it is possible to solve the problem by themselves cooperating in a group or a specialist have to be consulted (for example the machine builder).This is possible now via Internet, because most of the modern controls of machine tools use operation systems like Windows NT with

a connection to Internet, and most of the machine builders offer on-line service, not only for maintenance problems but also to give advise to solve manufacturing problems.
With this support and their experience when running the system total productive maintenance will be effective for enhancing the availability of manufacturing systems.
Often expert systems are in use to instruct the operators to detect and to remove faults or repair parts of machines and manufacturing devices. But, if even experienced operators are sticking long time on advises of these systems their competence is fading away. They loose their understanding what happens and what to do.
An alternative got developed by and John & Marzi (2001). Operators use the information provided through a multi agent support together with their experiences what to do to achieve again the normal operating state of the manufacturing system (Figure 7). Two software

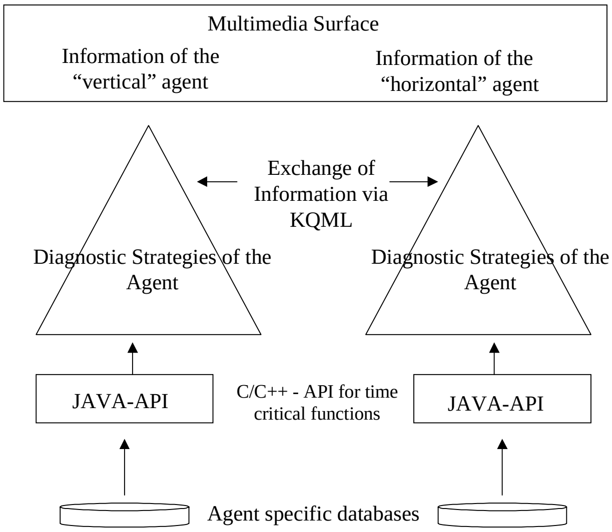

Fig. 7. Architecture of the software agent system (Marzi & John, 2001)

agents are cooperating together and with the operators. A "horizontal agent" are looking for faults along the same level of a component-tree regarding the functional dependencies between the components. The component-tree represents a hierarchical order beginning with the machine itself until the smallest component. A "vertical agent" looks for faults in a component and its sub-components. Both agents use implemented specific strategies based on information of the machine builder and experiences of former problem solving. Obtained experiences when running and maintaining the agent system can be fed to the knowledge base (enhancing or altering the component-tree) thereby enhancing step by step the performance of the system. Also the diagnostic strategies can be enlarged or changed by the operators to make the system more effective and adaptable to new challenges. The support could also be used to point to approaching inadmissible system states for indicating the limit of the space of acceptable performance. This is possible with the help of a simulation tool that is not yet developed.
It should be stressed here again: the MAS serves as a support system, leaving the strategic decisions to workers. To achieve this, software designers are challenged to participate the experienced workers in designing such systems.

4. SHOP FLOOR CONTROL

Shop floor control is called the link between the planning and administrative section of an enterprise and the actual manufacturing process. In SME´s with usually few staff to perform planning and setting up of tasks, shop floor control becomes the information backbone to the entire production process.
What SME´s need are low cost control means not only to avoid more or less complicated and expensive technology with respect to investment and maintenance but the work-organization should be effective.
Of course the shop floor needs software support to enhance the flexibility and productivity. But support is to be stressed, not determination what to do by automatic decision making.
In small batch or single production (moulds, tools, spare parts) one needs devices for a dynamic planning. Checking all solutions to the problems arising at the shop floor, while taking into account all relevant restrictions, short term scheduling outside the shop floor either by manual or automatic means is not possible.
It is without sense to schedule the manufacturing processes exactly for weeks ahead. One needs devices which are capable of calculating time corridors. The shop floor can do the fine-planning with respect to actual circumstances much better then the central planning. Human experience regarding solutions, changing parameters and interdependencies is the very basis of shop floor decisions and needs to be supported rather than replaced. Figure 8 shows a network linking all relevant modules to be used by skilled workers at the shop floor. Apart from necessary devices as

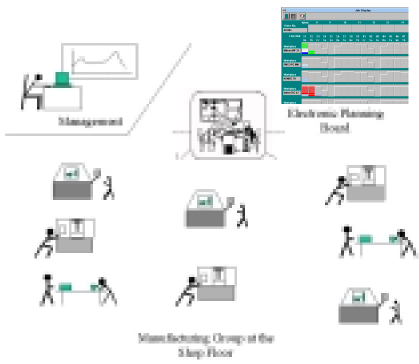

Fig. 8. Modules of a Shopfloor Network

tool-setting and others an electronic planning board is integrated. The screen of the board is available at all CNC-controls to be used at least as an information on tasks to be done at certain workplaces to a certain schedule. As all skilled workers as a group are responsible for the manufacturing process they have beyond the access to information the task of fine-planning of orders they got with frame data from the management. Therefore they use the electronic planning board at the CNC-controls or alternatively at a PC besides.
Using an electronic planning board at the PC screen based on a database the decisions of the workers with respect to shorten the through-put time or to schedule delivering can be first simulated to consider the access of tasks to available resources. So disturbances at the shop floor (breakdown of machine tools, not just available tools, just missing personnel) can be ruled out.
Sawaragi et al (2000) introduced an interface agent as a associate for human operators, preventing them from a flood of data for decision making and on the other hand avoiding computer based instructions for taking action. According to Sawaragi et. al. an interface agent is a semi-intelligent software that can learn by continuously "looking over the shoulder " of the operators as they are performing actions. The agent has to coexist with the operators so that it can evolve by itself as the operators proficient level improves, but in a way to stimulate the operators creativeness, rather than to replace them by itself after some time. To be a human collaborative an interface agent has to make decisions analogous to humans. Sawaragi proposes a shift from classical normative decision making to a naturalistic decision making concentrating on the proficient operators situation assessment ability looking at a situation and quickly interpreting it, using their highly organized base of knowledge recognizing and appropriately classify a situation.
Again we are focusing on a support for human operators with software agents for job-shop scheduling. A manufacturing system is a net of different machine tools and handling devices. It processes information and material. It have to be operated to achieve an optimum with respect to material and time resources regarding the tasks to be done. This represents the normal work practice and may be defined as normal job-shop scheduling. Many attempts have been done to solve this combinatorial problem, like CSP (Constraint Satisfaction Problem). An overview and discussion give Dimopoulos & Zalzala, 2000). But static scheduling problems are not mapping the real world practice. Additional express orders or just not available resources causes a fluctuation around this normal work practice or performance of the manufacturing system. Inappropriate planning and control caused by time and costs pressure, tight resources on personal, or deficiencies by illness, all unexpected issues are moving the system to the limit of the space of acceptable performance. This can occur unnoticed and will be perceived only when the quality decreases, times of delivery are exceeded or through put time increases. A decision support has to intercept such movements of the normal work performance against the limit of acceptable performance. Attempts have been made to formulate these problems as Dynamic Scheduling, using machine learning methods or extensions of CSP discussed also by Dimopoulos & Zalzala (2000). But all these attempts are not satisfactory respecting computation time and probably cannot take into account all possible uncertainties.
Therefore a scheduling support with soft constraints developed by Fauser (www.fauser-ag.com), called JobDispo, results in an electronic planning board for the shop floor used by the group of operators as mentioned above.

6. OUTLOOK AND CONCLUSIONS

A low cost intelligent automation is based on a quick information providing and communication between customers and suppliers as well as inside the enterprise. Despite of partly expensive software the complete costs of the manufacturing have to be considered. The reconfiguration and the maintenance of automation systems can be very time consuming whereas the direct costs of the manufacturing itself are decreasing. Human skill and experience can reduce idle time when supported intelligently with suitable automated equipment like machines with job-shop controls, electronic planning boards at their workplaces and a support for fault detection and proactive maintenance.

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