

# Enhanced Automation Strategy for 5-Axis Vertical Machine Tools

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**Abstract:** Today's production systems face the challenge of adapting quickly to changing market conditions, which can vary from large to small volumes and from mass production to mass customization. Flexible automation meets most of these requirements and offers solutions. It brings together all the resources needed for continuous or customized production, from the supply of workpieces, fixtures, tools, NC programs and logistics plans. Pallet systems play a key role in the automation of the production process as they enable the smooth flow of workpieces between pallet storage and machining centers. In this paper, an analysis of the pallet system market was carried out, revealing that a large number of pallet systems are installed from the front of the machine. This front-facing installation makes access to the machine difficult, especially if the production system is to be adapted to frequently changing conditions. In this article we present a new approach to configuring a pallet system for vertical five-axis machining centers that further increases flexibility and adaptability. The new concept of palletization of vertical five-axis machining centers presented here is based on installing the pallet system at the rear of the machine, leaving the front of the machine free.

**Keywords:** automation; flexible manufacturing cell; flexible pallet changer; modular storage; reconfigurable manufacturing system; 5-axis vertical machine tools

## 1 INTRODUCTION

Enhancing the efficiency and productivity of production facilities increasingly relies on the adoption of new technologies and the automation of processes. Simultaneously, the rise of individualism as a social trend has led to a growing demand for personalized products tailored to customers' specific preferences. This shift towards customization is driving not only an increase in product variants but also higher product complexity, placing additional pressure on productivity. As a result, flexible automation has become indispensable, requiring production systems to feature adaptable components seamlessly integrated into dynamic and complex manufacturing structures. To remain competitive, manufacturers must adopt comprehensive global strategies that optimize their role within the global supply chain while simultaneously enhancing internal productivity. Therefore, it is necessary to closely monitor trends on the world market, such as:

- shorter product service life,
- greater number of product versions,
- size reduction of individual production series,
- greater influence of customer's needs in process of shaping products,
- frequent changes of customer need due to market competition,
- rapid production changes and cheaper products of higher quality,
- strong international competition.

It can be seen from the above that the market demands increasing productivity, high quality and flexibility at a low price. These fundamentally conflicting demands on production machines and systems present significant challenges to address simultaneously. Nevertheless, achieving an optimal balance among productivity, flexibility, quality, and cost is essential. One way to meet the demands of the market is through modular production systems and automation systems whose capacities are easy to change and adapt and whose functionality can be changed for a new type of product in a short time and at minimal cost. Furthermore, with the growing trend to increase the volume of personalized production, the

reconfiguration of production systems is becoming increasingly important [1]. A large number of scientific and technical papers address those problems of designing and implementing reconfigurable production systems, but so far no high-quality and optimal solution has been proposed [3, 4, 9]. When designing the structure of a flexible production cell, it is necessary to know the family of workpieces for which the system is intended and the conditions for which it is designed [1]. Conditions may change over time, and the question arises as to how to meet unknown or uncertain requirements with a single, fixed production system over the entire life cycle. There is no known and established systematic and continuous process that enables SMEs (small and medium-sized enterprises) to introduce and change production systems to cope with unpredictable market demands [1]. The question arises as to what kind of reconfigurability would be necessary and satisfactory for flexible production systems to adapt over time to the real needs of work in small and medium-sized enterprises that do not have large batches and fixed production, but must adapt to market conditions in a very short time [2, 11, 14]. Therefore, this article investigated whether economically viable, personalized and serial production is possible on flexible production lines with automated pallet handling systems. This article focuses on the development of a conceptual solution to increase the reconfigurability and adaptability of production cells for SMEs that want to maintain a high level of quality, variety and satisfactory productivity for personalized, small batch and serial products. The methodology and approach to problem solving will be based on the analysis of existing systems on the market and their trends aimed at increasing flexibility and reconfigurability. The basic criterion in setting up the concept will be to increase the extensibility and adaptability of the system as a compromise solution that includes economically justified personalized production, small series and serial production.

## 2 STRUCTURE OF FLEXIBLE MACHINING CELL

Any production system, if well designed, must guarantee the quantity, quality and variability of the product within its structure. However, the requirements of

each industry are very different, so there are many different solutions on the market. Market conditions require an individual solution for optimized flexibility and efficiency of production systems depending on the specific needs of the customer. The flexible manufacturing cell (FMC) is suitable for the manufacture of products with a large variety and smaller batches. It attempts to increase plant utilization by reducing idle time, i.e. increasing processing time. The FMC consists of a mechanical and a software part. The basic mechanical structure of the FMC is shown in the figure (Fig. 1). The mechanical part of the FMC consists of a processing machine with automatic tool change, a pallet changer, a pallet with clamping device, a pallet storage, loading and unloading stations, tools and a control system for process monitoring and control.

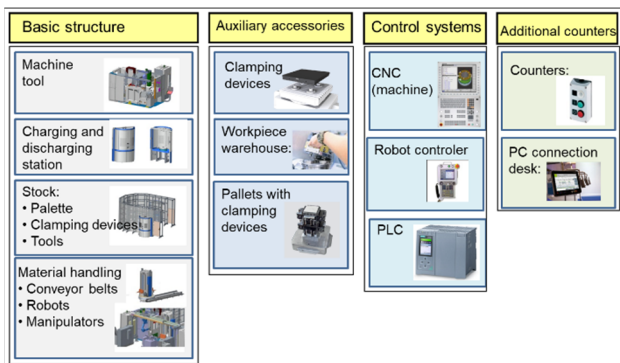


Figure 1 The basic mechanical structure of a flexible machining cell [5]

The mechanical components that form the basic framework of FMC are formed during the construction of the production cell (Fig. 2). Their structure can be modular and reconfigurable to adapt to the current needs of the market (adding a new workstation, increasing pallet storage capacity, increasing tool storage capacity, adding new clamping devices, etc...). Their modification requires additional investment and time, which is often a limiting factor for small and medium-sized companies.

FMCs are complex, dynamic systems that require active control and monitoring of the processes and all components in the system. There is an intensive exchange of information between the individual systems in the FMC (Fig. 2). Digital control systems, monitoring and diagnosis of process conditions in FMC are becoming increasingly important depending on the degree of automation and flexibility, especially in production systems intended for the manufacture of a large number of different products in small quantities. The FMC management structure should enable the optimal and timely functioning of all elements of the production system in order to achieve the set goals. The FMC management system works on several different management levels to ensure efficiency and flexibility. Each level should have a database that is modular and designed to be independent and focused on its areas of activity (Fig. 3). Production cell management systems plan and organize order processing, control the flow of workpieces and the provision of resources (tools, NC data, operating resources, etc.) and the transfer of the necessary production information to processing machines, pallet changers or manual workstations. The resources required for production, such as raw materials, NC programs, fixtures and tools, must be provided in good time and in

sufficient quantities so that the FMC can work continuously and autonomously. The demands on the production control systems increase considerably when a large variety of workpieces are machined in small quantities. The aim is to achieve maximum productivity despite small batch sizes and a wide range of part variants. FMC must be safe, reliable and autonomous. To achieve this, online control and monitoring of the process is required. Online monitoring, diagnosis and optimization of the process management system through process monitoring, detection and diagnosis of errors and downtime, and preventive monitoring of system status, play a key role in ensuring autonomous execution of work tasks.

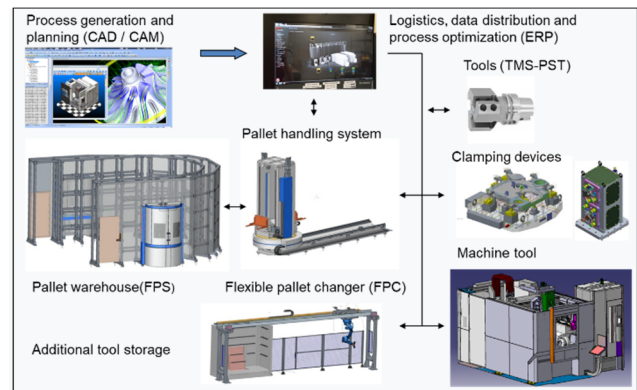


Figure 2 Schematic representation of the FMC components

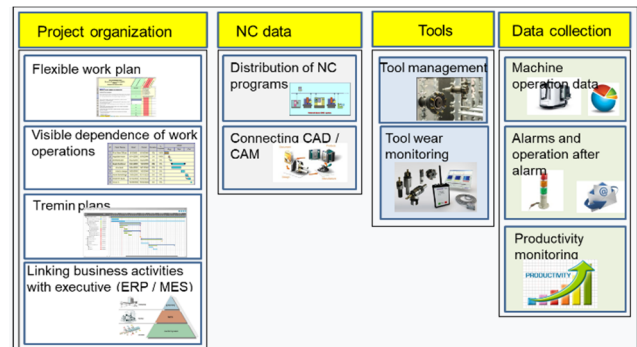


Figure 3 Software structure of a flexible production cell [5]

The control system therefore controls the transportation of workpieces, pallets, tools and accessories as well as the transfer of production data to the machine. It also plans the sequence of orders by starting automatic NC machining, simulating the production process, calculating resource requirements and recording production process data.

### 2.1 Analysis of Pallet Handling Systems

Pallet warehouses, combined with automatic tool and pallet changing systems, are driving the development of flexible automation. In conjunction with intelligent logistics and diagnostic systems, this approach ensures maximum utilization and efficiency of machine tools. The average utilization of the machine when using process automation is significantly higher than without automation. According to *Hermle*, the increase in machine utilization is up to 35% [21] (Fig. 4).

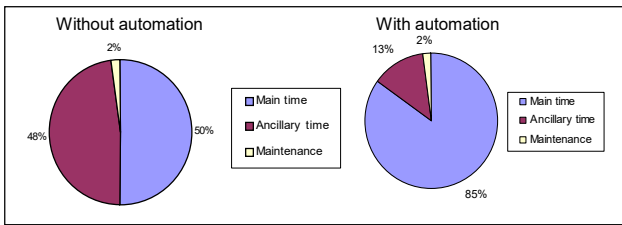


Figure 4 Distribution of processing time [21]

An integral part of the flexible manufacturing cell (FMC), in addition to the automatic tool change on the machine, is the pallet handling system, which transports the pallet from the storage station to the processing station and vice versa, thus ensuring a continuous and automated production cycle. Pallet handling systems can be designed as a circular or linear pattern, depending on the shape of the storage area for pallet placement (Fig. 5). The technical performance options range from simple classic pallet changers with two pallets integrated into the machine (Fig. 5a) to rotating pallet storage systems with multiple pallets on one or more levels equipped with pallet changers (PC) (Fig. 5b and c). Linear pallet storage systems are capable of storing a large number of pallets and connecting a large number of machines. Round storage variants, on the other hand, are characterized by their space-saving design. There is a plethora of pallet system suppliers on the market, each offering unique solutions for a wide range of industrial requirements.

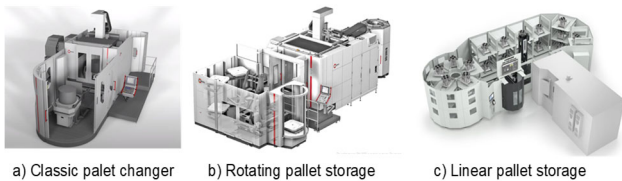


Figure 5 Visual representations of different types of pallet handling systems

Tab. 1 provides a comprehensive overview of some of the leading manufacturers of pallet systems in this area. Specialized pallet system manufacturers offer customized palletizing solutions and tune both the hardware and software to integrate seamlessly with machines from different manufacturers. Some machine manufacturers offer their own palletizing system solution together with their machines.

Table 1 Analysis of the market of pallet systems

Company	Rotary pallet system	Linear pallet system
Libherr [19]	RLS	PHS 800-1500
Fastem [17]		FPC 750-3000
Erowa [25]	Robot Dynamic 500-250-150L	
3R [27]	Transformer WorkMaster	
DMG [22]	PH50-2000	LPP 40-2000
Hermle [21]	PW100-2000	Handling system HS flex
Grob [20]	PPS-R100-300	
Heller [24]	Fastem/Libherr	Fastem/Libherr
Mazak [23]	MPP	
Mikron [30]	3R pallet changer	3R/Teh cut

All manufacturers offer similar round pallet systems, especially when the pallet system is used for a machine. These systems have a high storage density, a small footprint, are modular and compact and can be adapted to

the customer's needs. Some manufacturers have specialized in the development and installation of pallet systems on machines, they adapt to different machine manufacturers and participate with them in the construction of complex flexible production systems (*Fastem, Libherr...*) (Fig. 6a and b), and some larger machine manufacturers develop their own pallet systems that are already adapted to the needs of their machines (*DMG, Grob, Hermel, Mazak, etc.*) (Fig. 6c, d, e and f).

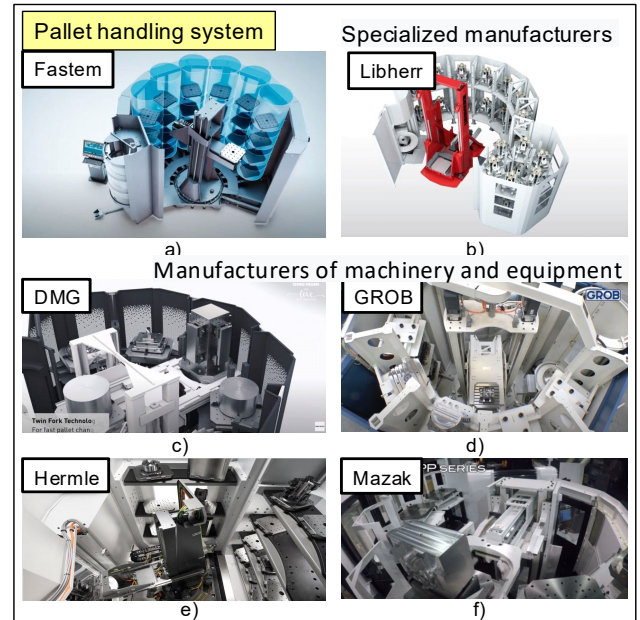


Figure 6 Representations of different types rotating pallet handling systems

When it is necessary to connect several machines in production lines, linear pallet systems are generally used. Each flexible production system is designed according to the customer's requirements, adapted to a specific product group and specific conditions in terms of production capacities and deadlines. Regardless of this, the pallet warehouses of all manufacturers are similar, modular and reconfigurable. It is possible to change the size of the space for storing pallets or add new spaces as needed, and to change the structure of the storage space according to current needs.

### 2.1.1 Reconfigurable Modular Pallet Storage

The automatic loading and unloading of pallets with workpieces and the automation of additional handling tasks are perfectly tailored to individual or series production. The choice of pallet storage form depends on the processing, the dimensions of the pallets and the environment. They can be rotating (Fig. 7a) or linear (Fig. 7b).

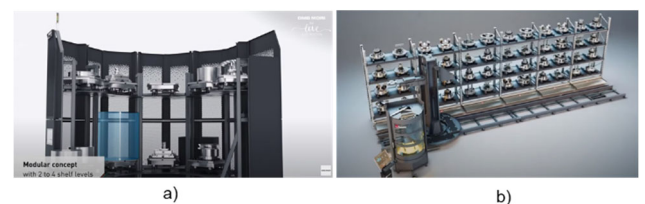


Figure 7 Forms of storage spaces

Depending on the production requirements and the available space in the production hall, the storage space must be adaptable. Scalability and modularity allow the subsequent installation of additional machine tools, receiving stations and the expansion of storage capacity according to production requirements.

Most manufacturers design their systems so that the layout of the pallet space can be flexible in terms of shape and height. The capacity and size of the warehouse depends on the size and quantity of pallets stored. The pallet with the unprocessed part is placed on the loading station and the pallet changer takes it to the warehouse or directly to the machine. The warehouse is filled and emptied while the machine is in operation. Pallet handling is controlled by a mainframe computer that prioritizes pallet movements according to the requirements of the production process (Fig. 8). The pallet must be provided with an identification tag, which must be read when the pallet is stored.

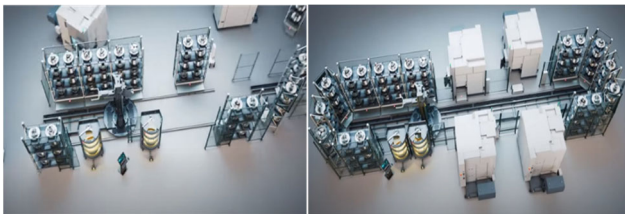


Figure 8 Examples of reconfigurable linear and circular pallet magazines

### 2.1.2 Pallet Changer

An integral part of the pallet handling system is the pallet changer, which enables automatic transportation of the workpiece from the storage station to the machining location and vice versa. It ensures a continuous and automated production cycle (i.e. without interruptions for the assembly/disassembly of workpieces), enables the exchange of a machined workpiece for a raw one, which significantly improves the efficiency of production equipment, saves manpower and floor space and ensures greater flexibility of production systems. Most pallet system manufacturers have developed pallet changers that are an integral part of the pallet handling system (e.g. *Fastem*, *Libherr*, *DMG*, *Grob*, *Mazak*, etc.) (Fig. 9).

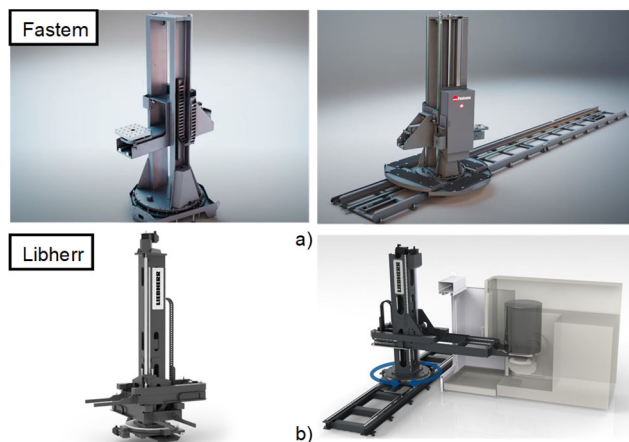


Figure 9 Examples of flexible pallet changer

The design of the pallet changer depends on the movements required for the changer to transport the pallets from the pick-up station to the storage area or machine. The

most common design of a pallet changer is based on a cylindrical kinematic structure equipped with a telescopic mechanism. If it is necessary to connect several machines in a production line, the cylindrical structure of the pallet changer is placed on a linear axis. The load capacity of the pallet changer depends on the pallets, the clamping device and the length of the required path of the telescopic arm. The pallet changer can be equipped with single-sided or double-sided forks. Some manufacturers equip their pallet changers with single-sided pallet forks (*Mazak*, *Hermle*, *Fastem*, *Erowa*, etc.), others with double-sided forks (*Libherr*, *Grob*, *DMG*, etc.). The double pallet changer has two pick-up forks located on telescopic mechanisms positioned on the rotation axis. It can perform two different functions:

- The telescopic fork can transport the stock part in one movement and reload the machine immediately after unloading the machined workpiece. This is particularly interesting for machining centers with direct loading without pallet changers or multi-machine systems. Compared to a single loader, the time required to change pallets is reduced by 50%, which is particularly important for shorter processing times and more frequent pallet changes. As the processing time is shorter, the double loader has a greater impact on the processing procedure.
- The double loader can be equipped with different transport forks for different pallet sizes. The forks can be changed automatically, making it possible to connect several different machine types and sizes. The modular pallet changing system designed in this way enables easy expansion if required.

## 2.2 Analysis of Design Flexible Machining Cell

In most current flexible manufacturing cells, the layout focuses on the positioning of the pallet handling system in relation to the machines. Pallet systems can be installed from the front, rear or side. The position depends on the space available and the configuration of the machine. Most of the pallets changing systems presented are installed at the front of the machine. Such an installation makes access to the machine more difficult when it comes to adjusting and maintaining the machine and if the pallet changer malfunctions. Some manufacturers try to minimize downtime due to difficult access to the machines from the front, i.e. they try to ensure access to each machine at all times in order to maintain productivity even during machine maintenance, manual activities of the operator when preparing the machines or tools required for automatic autonomous work (Fig. 10).



Figure 10 Visual representation of the pallet system in front of the machine [19]

One of the possible solutions to the problem is the installation of a pallet system from the rear [29, 30], (Fig. 11). In this case, the front side of the machine is free and

access to the machine is enabled. The system includes a pallet changer that moves linearly to the rear of the machine, where a rotary magazine with 6 pallets is located on one level. The concept does not allow for an increase in pallet storage capacity, the changeover is slow and requires free space within the machine for rotation. The layout of the machine is larger. The lateral placement of the pallet system prevents lateral access to the machine. It is significantly dependent on the configuration of the machine. No such installation is known.

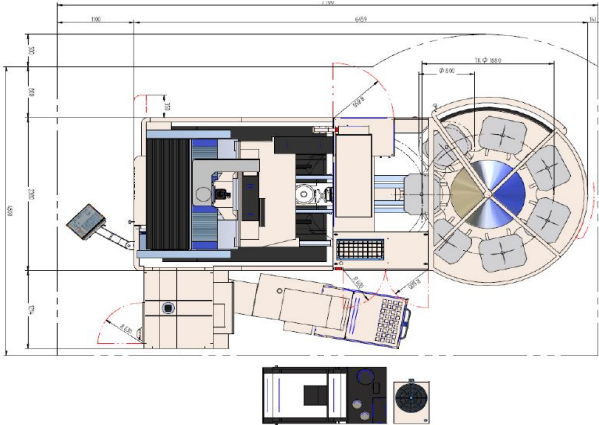


Figure 11 Schematic representation of the pallet system from the back side of the machine [30]

Building on the preceding analysis of existing flexible cell structures, the next chapter presents a concept that aims to improve the design of production cells. This concept is designed to support both manual and automated operations, enabling cost-effective personalized and serial production within the same facility. This dual capability is particularly valuable for small and medium-sized enterprises (SMEs), as it provides them with flexibility and economic efficiency when adapting to different production requirements.

### 3 A NEW APPROACH TO DESIGN A FLEXIBLE MACHINING CELL

Existing flexible systems have a well-defined structure optimized for medium-sized batches of similar workpieces, characterized by stable processes, standardized tools, validated clamping devices, and precise scheduling (e.g., for components like engine blocks, cylinder heads, and steering knuckles). However, integrating new production processes into these systems is complex and time-intensive, requiring multiple stages and the expertise of specialists to configure technology, select tools, design clamping setups, define operations, program NC machines, and schedule tasks. This makes system adaptation both slow and costly, particularly for individualized or personalized production, where the high preparation costs frequently outweigh the product's value, rendering the process economically unviable. Consequently, product personalization exerts additional pressure on the system's autonomy, flexibility, and adaptability in real-world conditions. This raises a critical question: can individualized, personalized production be profitably achieved within automated production systems? In personalized production, especially for small or customized batches, one of the biggest challenges is to test

CAM-based technologies under real-life conditions, where many critical issues are often left unaddressed. While CAM simulations define the structure of a technology, they do not guarantee process stability. Factors such as chip removal, clamping stability, machine rigidity and cutting conditions are ignored - all important factors for reliable operation. For processes with multiple tools and different operations (e.g. drilling, milling, reaming), a practical test is crucial before full automation. Manual machine control allows operators to adjust strategies and address critical issues, but in automated flexible cells, these issues must be tested and resolved in advance to avoid risks in production. As a result, personalized manufacturing and testing often cannot be seamlessly integrated into automation. To solve this problem, it would be beneficial for flexible production systems if specific stations could switch to manual mode for testing or customized work. In many systems, access to machine machines at the front is obstructed by pallet setups, making it difficult to test technologies. A more practical layout would place the pallet systems at the rear, improving accessibility. This paper introduces a new concept for flexible palletized cells, enabling easier separation of individual machines and seamless transitions between manual and automated operations, detailed in the next chapter.

#### 3.1 Proposal for the Automation Concept of a 5-Axis Vertical Machining Center

When analyzing existing market concepts, a design concept for FMC was identified that is in line with the objectives of this paper. In particular, the concept of placing the pallet system in the rear area supports the idea that certain machines within a flexible production chain can be operated automatically or manually depending on current needs. The concept focuses on the installation of a pallet system at the rear of vertical five-axis machining centers. The proposed conceptual solution enables technology testing, tool validation, fixture verification and collision detection without interfering with the automatic operation of other machines in the production chain.

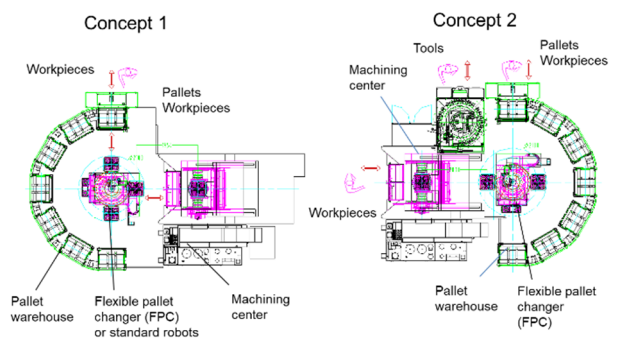


Figure 12 Schematic representation of the pallet system from: front (a) and back of the machine (b)

With this approach, the structure of the equipment and the operating mode can be reconfigured by software based on real-time requirements. This FMC setup and structure offers the potential to expand storage capacity and link multiple five-axis machines together, creating more complex, flexible production systems. Fig. 12 shows two layout concepts for installing the pallet system.

By comparing the presented concepts for the installation of palletizing systems from the front and from the rear in vertical 5-axis machining centers, the following advantages and disadvantages of the proposed installation solutions can be highlighted:

**a) concept 1**

- the pallet handling system is located on the front side of the machine,
- access to the front of the machine in manual operation is disabled,
- automation downtime causes machine downtime
- machine downtime prevents automation,
- when multiple machines are integrated, then the automation downtime causes the entire system to fail,
- difficult to separate the machine if it needs to be serviced,
- the telescope of the pallet changer needs a much smaller stroke than when it is placed on the back of the machine.

**b) concept 2**

- the pallet handling system is located at the rear of the machine,
- the front is free to operate in manual mode,
- automation can be switched off each machine separately when not in use or serviced,
- technology testing by the operator is enabled,
- when several machines are integrated, it is possible to switch off the operation of one or more machines when they are serviced or equipped with new tools, while other machines remain in automatic mod,
- mixing manual and automated work, which leads to the economically justified production of personalized products that are performed manually, while the rest of the equipment in the system simultaneously retains the possibility of automated work,
- the telescope of the pallet changer needs a larger stroke than when it is placed on the back of the machine.

The proposed concept of the flexible production cell improves the reconfigurability of the system and enables a more dynamic influence on common operational elements, such as the flexible use of components and the deployment of personnel as required. The work structure adapts fluidly to production requirements and supports not only small batch and series production, but also economically viable, personalized manufacturing. This approach not only streamlines workflows, but also gives operators more opportunities to intervene in the process. However, when implementing this concept, certain restrictions must be observed and specific requirements must be met to ensure practical application. The next chapter describes the approach to overcoming these limitations and the necessary component requirements for a viable system implementation.

### 3.3 Adjusting the Layout of the Machine

A prerequisite for the application of the concept is a change in the layout of the machine. Depending on the configuration of the machine, the length of the machine should be shortened as much as possible by redistributing the peripheral equipment (electrical cabinet, hydraulic unit, tool changer and tool storage) to facilitate access of the pallet changer to the pallet changer. Fig. 13 shows a change

made by Mikron to machine layout of the machine's peripherals. The redistribution of the peripherals has shortened the machine by 1400 mm, which has increased the machine width by 800 mm. This redesign of the machine reduces the distance required by the pallet changer to change the pallet from the rear from 3300 mm to 1900 mm. For a 5-axis vertical machining center configured in this way, the flexible pallet changer should be equipped with a telescopic mechanism that provides the required strokes and load capacity. As there are no changers on the market with such a performance spectrum, a flexible changer was developed as part of the EU development project [7], which is described in the next chapter.

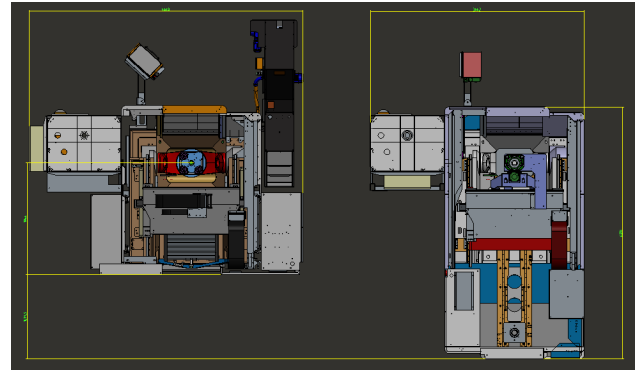


Figure 13 Changing the layout of the machine [30]

### 3.2 Special Flexible Pallet Changer

The pallet changer must ensure precise positioning of the pallets on the machine's worktable. It performs its tasks in a limited, narrow working space and transports large masses. Handling pallets from the rear of the machine requires longer linear strokes of the telescopic mechanism compared to the linear strokes required for installation from the front of the machine. It is desirable that the pallet changer is equipped with two working forks to reduce the process of changing and transporting the pallet from the warehouse to the machine and vice versa. If it also has interchangeable forks, the same changer can be used for different production systems (different pallets).

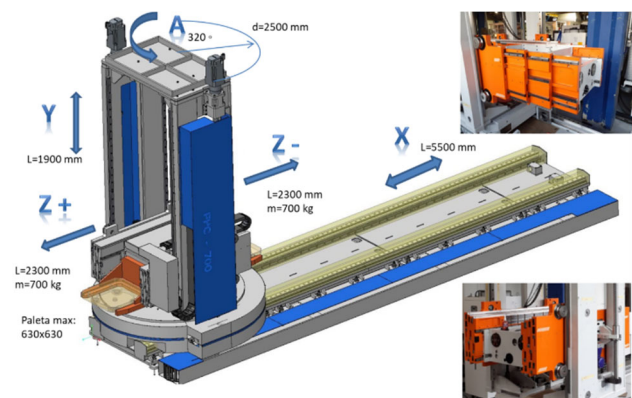


Figure 14 Flexible pallet changer (FPC 700) [7]

As part of the EU development project [7], a flexible pallet changer was designed that can handle pallets of different sizes (max. 630 × 630). The flexible pallet changer (FPC-700) is a cylindrical kinematic structure with a built-in special telescopic mechanism. The special telescopic mechanism enables linear movements of up to

2.5 meters to one side or the other from the pivot point. The minimum rotation radius when changing pallets is 2.6 meters, so the developed flexible pallet changer requires much less space for pallet rotation than most competitors. The load capacity of the flexible pallet changer is  $2 \times 700$  kg. When placed on a linear axis, it is possible to connect several machines to it in a flexible production system (Fig. 14).

The developed flexible pallet changer with the performance described above, together with the modified machine, enables the implementation of pallet systems that can be realized in the proposed FMC concept. In the next chapter, the application model of the proposed concept is presented.

#### 4 FLEXIBLE MANUFACTURING CELL WITH NEW PALLETIZATION CONCEPT

Most manufacturers aim for new system architectures capable of producing multiple products simultaneously while addressing current system limitations. Automated pallet storage and transport systems are typically tailored to each machine and customer's specific needs. The proposed FMC concept, discussed in the previous chapter, targets reconfigurable mixed production that retains the flexibility and efficiency of current systems for serial and small-batch production, yet can also accommodate economically viable personalized production. In this setup, individual machines within the production cell can be seamlessly activated or deactivated via software without affecting other machines. If a process spans multiple machines, specific operations can be rerouted to other cells, allowing disconnected units to support other tasks such as personalized production, testing, or maintenance. The system's structure can be reconfigured as needed, adapting fluidly to shifting demands. However, a key constraint lies in the fixtures, which are closely tied to specific technologies and tools and require separate management. To fully unlock flexible cells' potential, prepared tools, fixtures, and technological programs must be available.

##### 4.1 Clamping Device

The use of clamping devices makes it easy to position and clamp the workpiece, increasing the accuracy of machining and the uniformity of production quality and fully automating the process. The basic prerequisite for using a clamping device in the process is that the clamping devices have been tested and verified. The tests include checking the clamping safety, repeatability, checking the collision of the tool with the clamping device, i.e. it must be checked that there are no critical points for the accumulation of French fries, which is particularly important in automatic operation. Clamping devices are manufactured for one or more workpieces [15]. The prices for clamping devices are not low and, together with the tools, represent a considerable investment. Clamping can be done mechanically or automatically using a medium (hydraulics, air, electric) (Fig. 15). Clamping devices and tools should be prepared in advance. The prepared and tested clamping devices are placed on standard pallets and the pallets with the clamping devices are stored in the storage area. For continuous machining of one type of

workpieces, if they are machined at only one machining station, there are at least two identical clamping devices. The number of clamping devices depends on the number of work stations and the number of different workpieces to be machined.

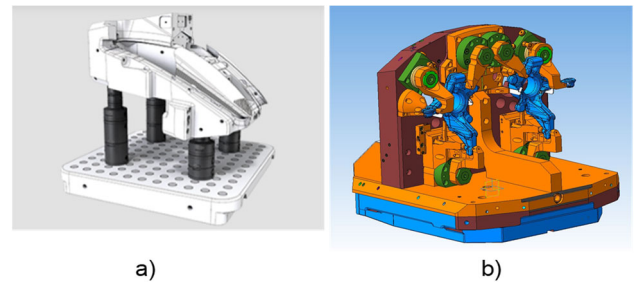


Figure 15 Visual representation of the clamping devices

##### 4.2 Flexible Manufacturing Cell with New Concept

Each FMC configuration depends on the space available and the family of workpieces for which the FMC is intended, as well as the conditions for which it was designed. Figs. 16 and 17 show two flexible production cells with two machining centers in different configurations, using the proposed concept of installing a pallet system at the rear of the machine and suitable for the production of small batches and individual parts. The front of the machine is free. The individual machines can be changed in software mode: manual or automatic. In automatic mode, the machine utilization can be up to 90% [21]. This means that the FMC works in three-shift operation, whereby all necessary resources must be provided. However, if one of the machines is used in manual mode to test technology, fixtures or tools, i.e. to create a personalized product, the operator is involved in the process while the other machine runs smoothly in automatic mode. This is suitable for small and medium-sized companies, as different tasks can be carried out simultaneously on the same machine.

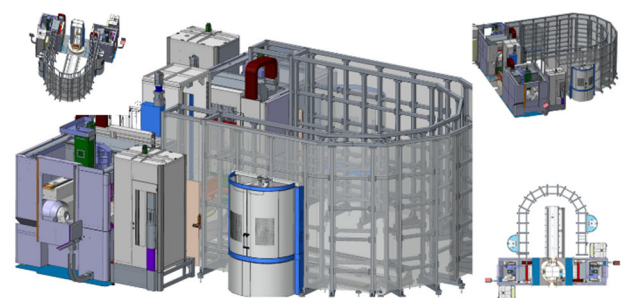


Figure 16 Visual representation of the flexible machining cell

One of the questions relates to processing times. If the machining time is short, the influence of the pallet change time on the utilization of the system is higher (e.g. the machining time for a pair of steering knuckles is about 6 minutes, (Fig. 15b). Changing pallets on a machine with the special pallet changer described above takes about 30 seconds, while placing the pallet in the storage location takes just over 30 seconds. It therefore takes no more than a minute to operate the workstation. In this case, the flexible pallet changer can operate several interconnected machines. The concept of flexible cells described in this

article was physically implemented as part of an EU project [7]. A special pallet changer was designed and the machines were redesigned by the manufacturer. The layout of the implemented flexible production line is shown in Fig. 17.

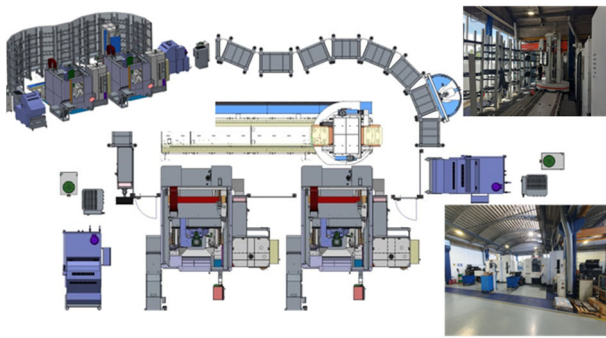


Figure 17 Flexible manufacturing system with two workstations [7]

## 5 CONCLUSION

In today's competitive world of factory production, it makes sense to optimize production processes and systems, reduce their unproductive time and adapt them to actual demand. This applies to almost all industries: from automotive and aerospace to general parts production, mold making and electronics. There are no off-the-shelf solutions therefore each system is unique. As the market is uncertain in terms of variety and capacity, efforts are being made to find optimal solutions that guarantee the expected flexibility, reconfigurability and variability of capacity. The automation of tool and pallet changes are indispensable elements in the development of flexible automation, together with intelligent logistics systems. The proposed concept offers an extension of the existing possibilities of flexible production cells by enabling a combination of individual and automatic operation according to current needs. However, in order to install such a system, it is necessary to adapt the structure of the machine and use a specially designed pallet changer that can meet the requirements of pallet transportation in a limited space. The prospect of such systems is closely related to the acceptance of the solution by machine tool manufacturers, i.e. those who are willing to change the layout of the machine configuration and adapt to the concept. A key component of such a system is a flexible pallet changer with the performance described above, which enables the implementation of such a concept. Further research would go in the direction of expanding the application possibilities in other types of production configurations with multiple machines, with different machines, with different types of pallets, with free transportation routes, where the flexible pallet changer should be adapted to automated guided vehicles (AGVs) and be an integral part of them.

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