"Pocket Factory": Concept of miniaturized modular cleanrooms

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Abstract

The manipulation and assembly of microsystems (MEMS) require accurate robots operating in a clean room environment. Available systems are bulky, thus requiring large ground surface for small components. Furthermore they have limited accuracy. The main objective of the 'Pocket-factory' project is to develop miniaturized and modular clean production units for microsystems and establish a methodology to quickly set them up.

Key words: microfactory, MEMS, Cleanroom, minienvironment, methodology

1. Introduction

Currently, manufacturing and microassembly processes for MEMS components are performed in cleanrooms that have a volume of several cubic meters. People working inside are the main cause of contamination, even if they wear special garments. This approach, for a limited throughput of production (i.e. about 100 parts/h), is expensive. On the other hand big machines lead to limited accuracy and require large ground surface.

This project proposes a new concept of modular and miniaturized clean systems for assembly of small MEMS components. The size of the included miniaturized clean rooms is typically 1dm^3 for each module, operating in standard external environment. A setup methodology will permit fast decision for the appropriate layout.

2. State of the art

The term "microfactory" was initially proposed by the Mechanical Engineering Laboratory (MEL) in Tsukuba, Japan in 1990 for their small manufacturing and assembly system [1]. It was a small factory with a milling and a press machine, a micro-lathe and a micro-transfer arm. It was a portable system with external dimensions of 625mm x 490mm x 380mm and it was targeting at applications that don't need any clean environment. Also others projects have realize small assembly and modular units for microassembly without cleanroom environment [2].

Many companies have realized "minienvironments" i.e. systems with a clean room environment including manipulators for micro-assembly or serving to store wafers or MEMS. The volume of these systems is several cubic meters (see **Fig. 1**) [3].

In our project we propose an innovative concept combining the two previous concepts: the small assembly microfactory and the clean rooms environment. It is an attractive concept for low throughput accurate production assembly under clean room conditions.

Fig. 1: An example of an modular min-environment of MEMS assembly by MA3-MST/MEMS Technology

To illustrate the Pocket-Factory concept we have realized a prototype using standard trays of 50mm x 50mm (such as waffle-pack or gel-pak®). The global concept is presented in the next paragraph. The main components of the Pocket-Factory and their functionality are then described in paragraph IV.

3. Pocket-Factory and modularity

An important aspect of the Pocket-Factory project is the high degree of modularity. The whole factory is subdivided into individuals cells (microbox), in which some elementary assembly operations are realized, before the sub assembly is transferred to the next microbox.

This concept is illustrated in **Fig. 2.** Several modular microboxes are put together for the assembly of a product. A transfer system permit to move the components between the microboxes. It is permitted to use any part feeding system or to execute high precision assemblies using synergy between the microbox robot and other high precision robots (i.e. Delta[3][4])

Each microbox is dedicated to several assembly operations (gluing, insertion, etc). In case of change of the production layout, it is easy to replace any microbox dedicated to one assembly task with any other.
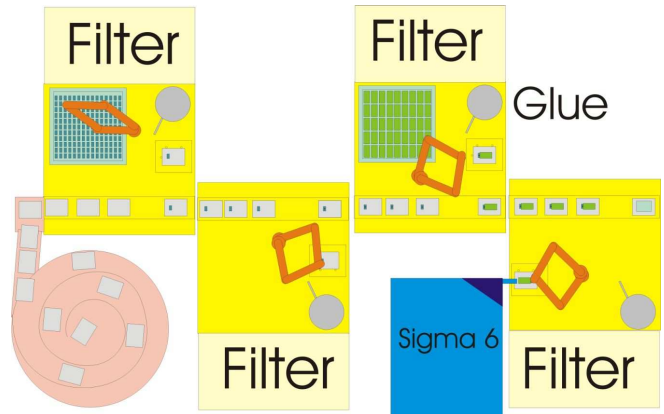
Fig. 2: The concept of the Pocket-Factory
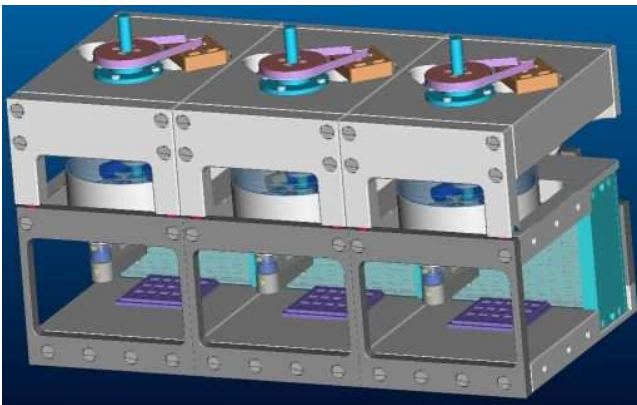
Fig. 3: A Pocket-Factory with three modules of microboxes

Combining several microboxes (i.e. already realized prototype (figure 4 and 6)), the Pocket-Factory may get a layout as in **Fig.3.** The robot of each microbox, after the assembly operations, can move the subassembly into the next microbox where the next robot will do the next assembly operations.

A methodology concept gets in consideration the special assembly needs like environment conditions (cleanliness, humidity, temperature, pressure, special gas (i.e. Ar, N_2, etc.) of each product. It proposes also a setup for the Pocket-Factory that satisfies these conditions.

The size of the components and the desired time of autonomy define the size of each microbox and the number and size of palettes to be used. If one assembly task is time consuming it is possible to use in parallel several similar microboxes in parallel. The methodology for the optimal design of the microfactory is explained in paragraph 5.

4. The parts of the Microbox

Typically a microbox (**Fig. 4**) has a useful volume of about one cubic decimetre and a clean class performance ISO 5 (class 100 according to the Federal Standards 209E). Several assembly operations will be realized in each microbox. The parts are then transferred to the next microbox for the next assembly operations (gluing for example). Each microbox is composed of several parts, dedicated to the assembly functions and to ensure the cleanness inside the microbox. These are:

- Entry ports adapted to the parts trays (palettes for example), which permit a clean transfer between microboxes and the room area.
- A robot for transfer of parts inside the microbox and/or for simple assembly tasks
- Sensors for process control
- An air filtration system, equipped with a compact laminar flow generator
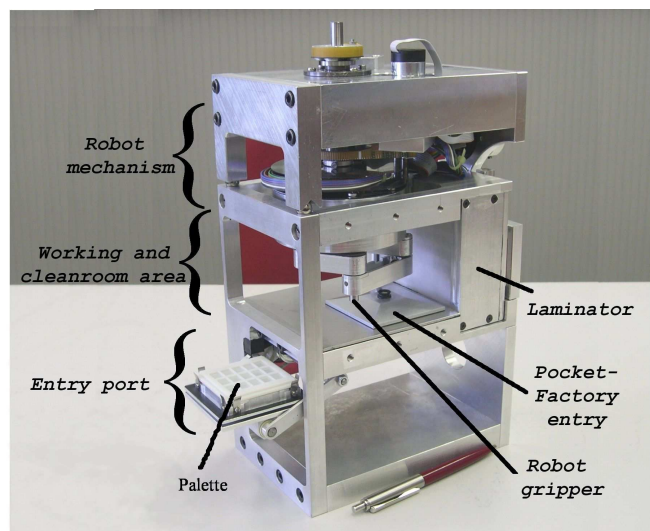
Fig. 4: The microbox is a module of the Pocket-Factory

In the next paragraphs we explain the functionality of these parts.

A. Entry port

An example of an entry port is a mechanism for introducing a 50 x 50 mm palette from the room non-clean environment into the clean environment of a microbox[5]. The palette serves to both functions, internal and external transport. Using this entry port the palette is opened inside the microbox without contamination, thanks to a clean air purging of the palette before the opening. The following images explains the procedure.

-   In the approach phase, the closed palette is placed in a self-aligning support (**Fig. 5a**).
-   In the final position of the loader frame, a small air leak space between the Pocket-Factory entry and the support of the palette permit to flushing air to flow and clean the micro-particles present on the side of the palette (**Fig. 5b**).
-   The robot uses vacuum to pick-up the Pocket-Factory door including the cover of the palette. When the upwards movement of the door with the cover starts, the small air leak space between the Pocket-Factory entry and the support of the palette is closed (**Fig. 5c**).
-   In the final step of this operation, the robot opens the door and the cover, and the components are in the clean environment of the Pocket-Factory (**Fig. 5d**).

Fig. 5a

Fig. 5b

Fig. 5c

Fig. 5d
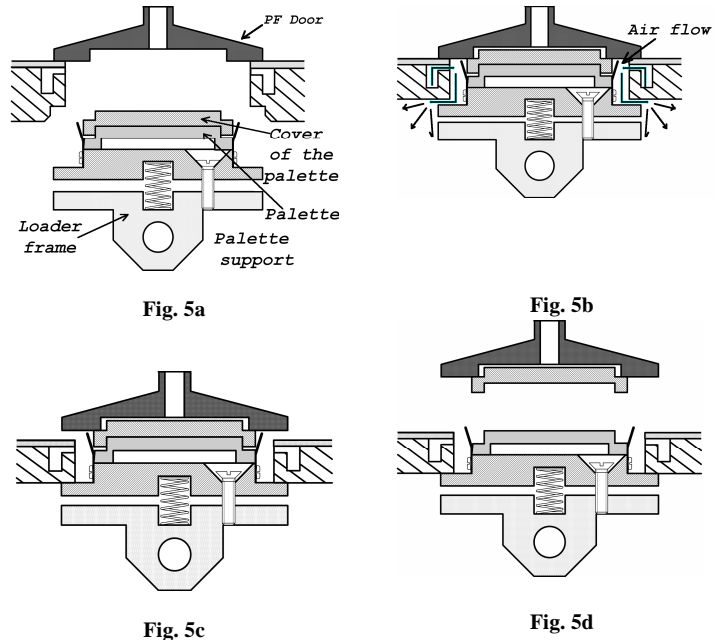
Fig. 5: Phases of introduction of the palette to the Pocket - Factory

B. Robot

For the assembly needs of the Pocket-Factory, each microbox has a small 4 degrees of freedom robot similar to a SCARA robot (x, y, z, and θz) as it is shown in the **Fig. 6**. It executes assembly and conveying tasks or collaborates with a high precision robot for more precise assembly. It serves to transfer parts inside each microbox and from one microbox to the next one. Moreover it is used to open the door of the entry port. It operates in the cleanroom environment class ISO5. Its workspace is a cylinder of 130 mm diameter and 20 mm hight. The robot itself has a size of 100x100x200 mm.

The actuators of the robot are situated outside of the clean area. If necessary it is possible to take the robot out for maintenance. The components pick and place is performed using vacuum.
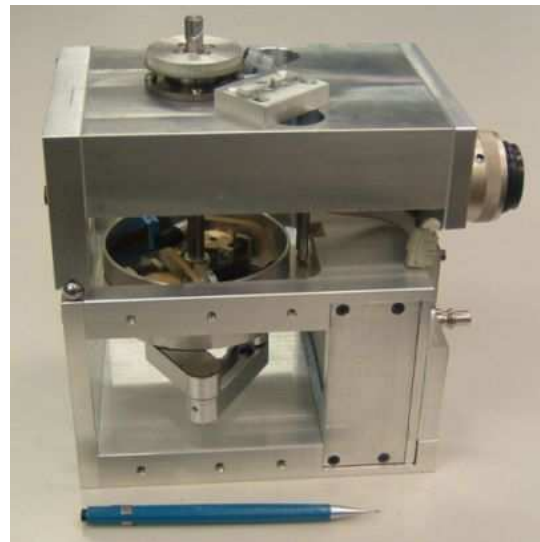
Fig. 6: The 4 DOF robot associated with a microbox

C. Sensors for process control

The manipulation and assembly of parts smaller than one millimetre need sensor control. The easiest method is to use vision systems.

In the PocketFactory a camera will recognise parts shapes and will give the information to the control system. Depending on the product to realise and the size of the microbox, the camera can be placed on the top of the assembly scene, or if it is possible or necessary under the assembly area. In this case this area must be transparent.
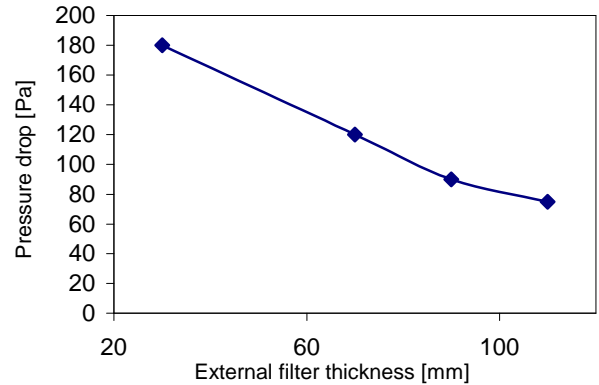
D. Clean air laminar flow system

This part is the heart of the clean air environment system. The goal was to produce a very compact filtrating system. Below we explain why it is not possible to make a compact system using the HEPA (High Efficiency Particulate Air) filters. Every filter is characterized by the Darcy low [6]:

$$\frac{Q_m}{A}=\frac{\Delta P}{\beta \cdot e} \Rightarrow Q_m = \frac{A \cdot \Delta P}{\beta \cdot e} \quad \text{where} \tag{1}$$

Q_m is the flow rate,
A the surface unit,
ΔP the pressure drop,
$1/\beta$ the permeability of the filter and
e the filter thickness.

Lower the permeability of a filter is, higher is the filtering efficiency. The HEPA filters have low permeability $(1/\beta)$. In order to reduce the pressure drop necessary for the filter, these filters have a large effective surface (A) but they are folded to reduce the frontal surface. So when we are referring to the external thickness of an HEPA filter, it is rather proportional to the surface (A) of the filter, than the thickness of the filter layer itself.

Fig 7 shows the relation between the pressure drop of a class H14 HEPA filter and its external thickness at 0.45m/s air velocity (measurement given by LogicAir S.A.).

The pressure drop that an axial ventilator can offer for a flow rate of 18m³/h is around 130Pa (it correspond at the needs of the Pocket-Factory, i.e. section of 100mm x 100mm with an air velocity of 0.5m/s). This means that at least, the filter thickness will be 70mm when new.

Fig. 7: The pressure drop of an class H14 HEPA filter at 0.45m/s in function of the external thickness of the filter

A typical fan thickness is around 100mm. So only for the filter and the fan the thickness of the ventilation system will be 170mm for a working area of 100mm x100mm x 60mm. We conclude that the use of standard HEPA filters for such small working areas leads to big fans or filter having very big surface (so an important external thickness). In both cases the ventilation system will have bigger volume than the working area.
In our project we decided to use compressed air and appropriate filters. The resulting pressure drop is higher (around 0.5 atm). It is possible to use compressed air from the facilities air network with constant debit. Pre-filters and air retaining system assure cleanliness of the compressed air.

Due to the small working volume the time to establish the clean conditions is very short (see **Fig. 8**). In this figure we can see three successive measurements of the air cleanness. Each measurement lasts around 80sec and we have represented the number of each size particles present in the air in the centre of the Pocket-Factory. All these measurements were realized in a non-clean laboratory. To establish the clean environment, we used the compressed air, filtered only by the Pocket Factory filter. After the second measurement the apparatus don't detect any more particles. So the time to cleaning setup is around 2 minutes.
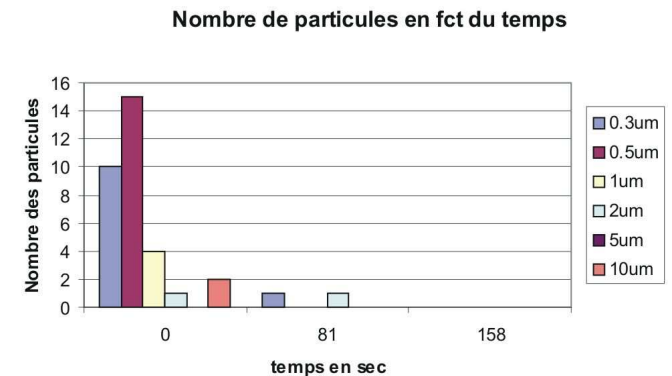
Fig 8: Number of particles regrouped by size, in function of the time.

The compressed and filtered air passes through a 20 mm thickness laminator and becomes laminar. The **Fig. 9** shows the air velocity measured at a distance of 15mm from the laminator. The average velocity is 0.4m/s with a standard deviation of 0.046m/s.

In a clean room it is essential to get laminar flow. The method to illustrate the laminarity of the flow is described in [7]: In the front of the laminator we tighten an iron wire and we apply oil on it. When we establish an electrical current, the oil is burned and thanks to smoke we can visualise the air flow. For better visualisation, we illuminate the smoke with a red laser light. In **Fig. 10** we see the result of this experiment in front of the laminator where the flow is laminar.
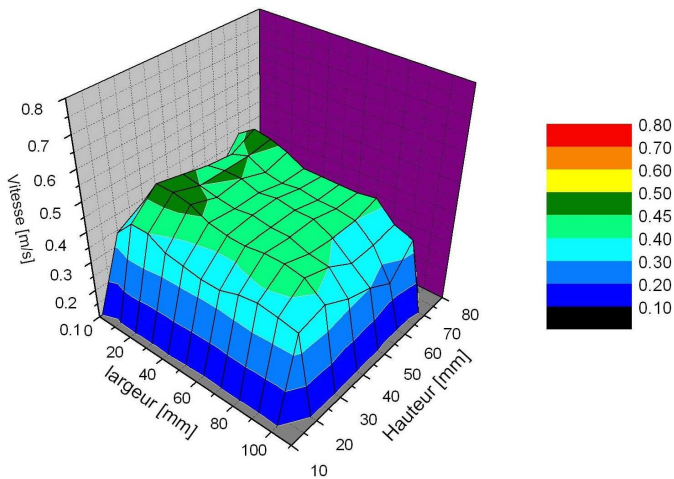
**Fig. 9:** Air velocity measured 15mm after the laminator

Fig. 10: This experiment shows the laminar flow inside the microbox

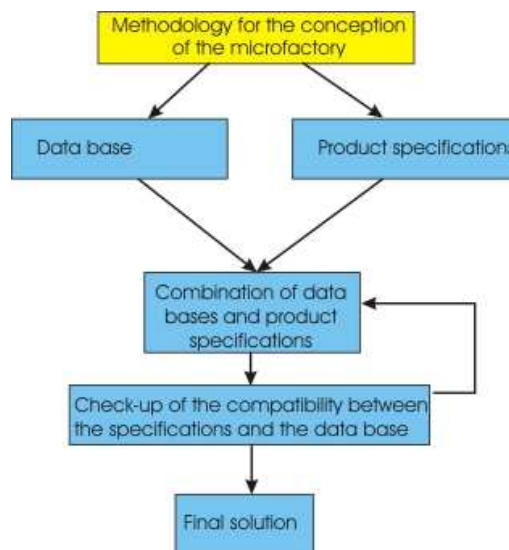## 5. Methodology for the conception of the microfactory

A dedicated methodology has been developed to find the best configuration for a Pocket-Factory. Its logical flow is described in the **Fig. 3**. The assembly of each component is realised in a separated microbox. Depending on the needs of the assembly operation of the component, each microbox can harbour one or more tools (insertion, gluing, curing, high precision manipulation, etc).

Some of factors that determine the size of the Pocket-Factory are the size of the components to assemble, the robots and the tools that are necessary for the assembly, the cycle time of these tools and their cost.
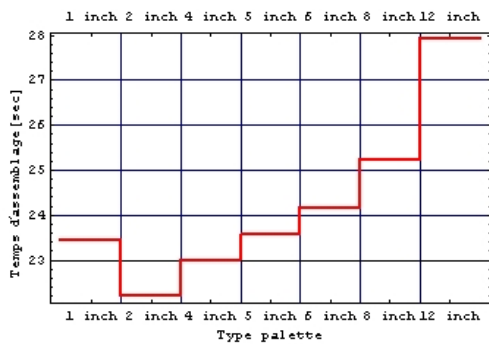
Fig. 11: Assembly time as function of the size of the palettes.

To illustrate this dependency we will explain the importance of the size of the palette. The use of a big palette to transfer the components increases the autonomy of the Pocket-Factory, but a bigger and more expensive robot will be needed, which will spend a lot of time to the components transfer. In the other hand, the use of a small palette needs a smaller robot, but we will spend a lot of time to load the palettes very frequently. With this example we can understand that for each product there exist an optimal configuration of the Pocket-Factory. In **Fig. 11** we can observe the influence of the size of the palette (here in inches) to the assembly time.

Fig. 12: Flow chart for the methodology of conception for the microfactory

To establish all the possibilities we have realised a program with Borland Builder C++, that helps the user to define the optimal size of the Pocket-Factory and the optimal combination of machines, robots and palettes adapted to his product. The flow chart of this program is illustrated to the **Fig. 12.**

This program is made of three parts. In the first part the user can introduce all the palettes, machines and robots that can potentially be used in the Pocket-Factory in a database. For each one the user introduces the size of it, its precision, cycle time and price as we can see in the **Fig. 13**
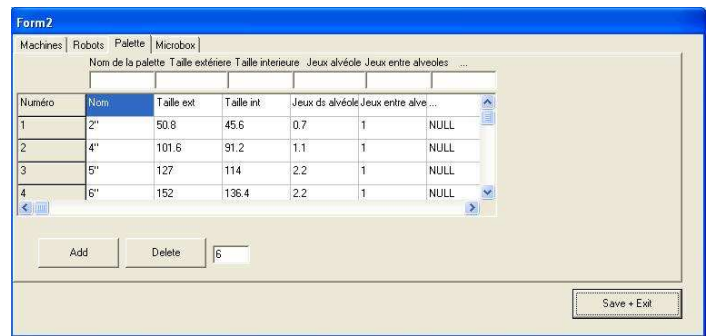

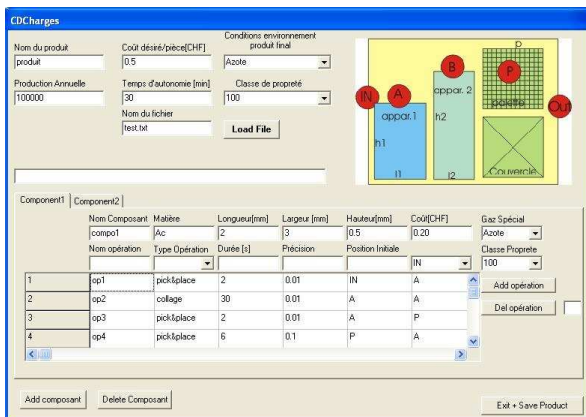**Fig. 13:** Window allowing the data base registration

Fig. 14: Window for the registration of the product characteristics

In the second part the user must introduces the information concerning the product that he wants to assemble in the Pocket-Factory. For each component it is necessary to give the characteristics of each operation (pick & place, gluing, etc) such as the operation precision, the type of operation or environment condition (property or specific gas conditions) as we can see in the **Fig. 14.**

In the third part the program does all the combinations between the palettes for the introduction of the components, the robots for the transfer of the components between the machines and the machines to use for the assembly or other operations. For each combination that respects the tolerance, the environment properties and the operation type, the program calculate the cost and the time of production. It is also possible to select the best combinations for each component in terms of time or cost. Then the user can choose which combination he prefers for the Pocket- Factory.

In the final part the program controls once more the compatibility of the users choice and if the time to produce for one microbox is less than the double of the others, it propose to double this microbox to increase the global throughput of the Pocket-Factory.

6. Acknowledgment

7. Conclusion

Pocket-Factory is a new production concept that combines minienvironments (small clean room) and the microfactory (small assembly system). It provides a clean room environment includes at least one micro assembly robot.

It is composed of modular stations called microboxes. Each microbox contains a small robot for assembly and transfer tasks inside microboxes and between them. Only a few assembly operations are realized inside each microbox. Then, the subassembly is transferred to the next microbox for the next assembly operations.

A prototype of this Pocket-Factory has been realized and the measurements have proven the feasibility of this concept. Regarding the cleanliness setup time to class ISO 5, it is less than two minutes.

To get an optimized assembly system a dedicated concept methodology leads to a quick set-up of a Pocket-Factory (in function of the size, the appropriates modules, the environment conditions, etc).

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