PocketFactory: a modular and miniature assembly chain including a clean environment

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Abstract - The manipulation and assembly of microsystems (MEMS) require accurate robots operating in a clean room environment. Available systems require usually large ground surface for small components and are bulky. Furthermore it is difficult to move it to another place. The main objective of the 'Pocket-factory' project is to develop miniaturized and modular clean production units for microsystems and establish a data base of needs and available accessories to quickly set up a production chain.

Index Terms - Pocket-Factory, minienvironment, clean room, assembly chain

I. 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 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 of machines and size of each module.

II. STATE OF 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 for fabrication and assembly of small components. It includes a milling and a press machine, a micro-lathe and a micro-transfer arm. This portable system with external dimensions of 625mm x 490mm x 380mm was targeting at applications that don’t need any clean environment. Various others projects have realized small assembly and modular units for microassembly without cleanroom environment [2].

In the other hand, 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 per module [3].

This project proposes 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.

To illustrate the Pocket-Factory concept we have realized a prototype that can be used with standard trays of 50mm x 50mm (such as waffle-pack or gel-pak®). The global concept is presented in next section. Section 4 describes main components of the Pocket-Factory and their functionality.

III. POCKET FACTORY AND MODULARITY

An important goal of the Pocket-Factory project is to achieve a high degree of modularity. The Pocket-Factory is subdivided into individual cells called microboxes. In the general case, the number of microboxes is equal to the number of components. Each microbox is used for the assembly operations of each component. Then, the sub assembly is transferred to the next microbox for the assembly operations of the next component.

This concept is illustrated in Fig. 1. Several modular microboxes are put together for the assembly of a product. A transfer system moves the components between the microboxes. It is possible to use any part feeding system or to

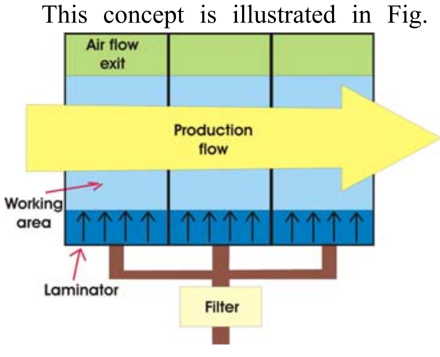

Fig. 1: The concept of the Pocket-Factory

execute high precision assemblies using synergy between the microbox robot and other high precision robots if they are clean room compatible.

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.

A possible layout of the Pocket-Factory may be seen in Fig.2 for a product with three components. The robot located in each microbox is used for assembly requiring low precision, but also for transferring the subassembly into the next

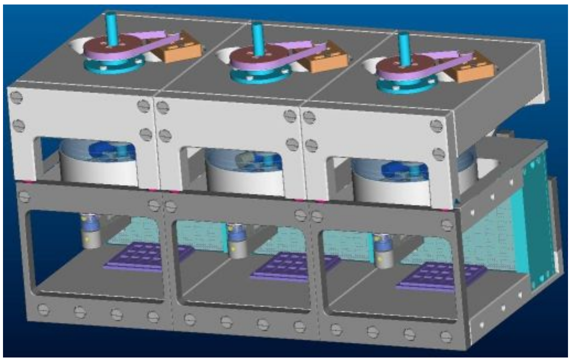

Fig. 2: A Pocket-Factory with three modules of microboxes

microbox where the next robot will pick it up and continue the assembly operations for the next component.

A dedicated program is used to help setting up the layout of the Pocket-Factory. It considers the special assembly needs like environment conditions (cleanliness, humidity, special gas (i.e. Ar, N_2, etc.), for each assembly step.

The size of the components and the characteristics of the robot to be used for their manipulation define the size of each microbox and the number and size of palettes to be used. If one assembly step is slower than the others, it is possible to use several similar microboxes in parallel. The methodology for the optimal design of the microfactory is explained in section 5.

IV. THE PARTS OF THE MICROBOX

The size of the microbox is adapted to the needs of the product to be assembled. To demonstrate the feasibility of a very small clean environment, we have realized a prototype (Fig. 3) that has a useful volume of about one cubic decimetre and a clean class performance ISO 4 (class 10 according to the Federal Standards 209E).
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

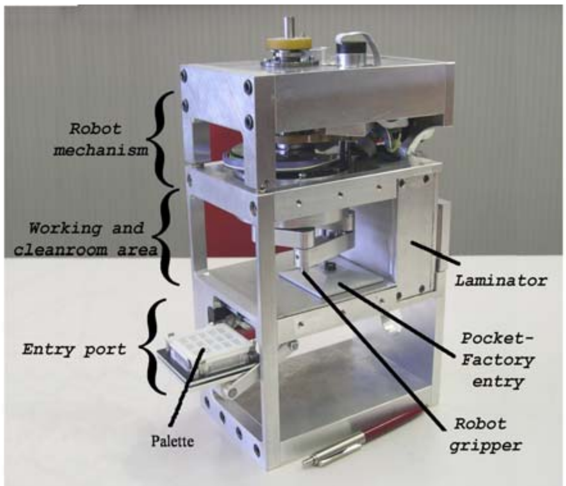

Fig. 3: The microbox is a module of the Pocket-Factory

The next sections 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 [4]. The palette is used to introduce non assembled components or to evacuate subassembly or finished parts. 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 palette is sealed inside a standard cleanroom by the producer of the components for instance. The following images (Fig. 4) explain this procedure.

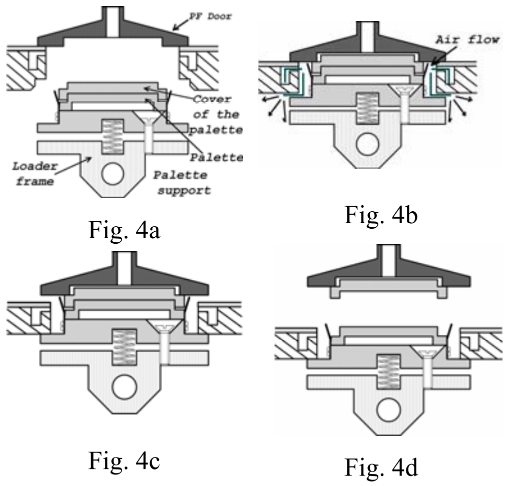

Fig. 4: Principle of the entry port system

- In the approach phase, the closed palette is placed in a self-aligning support (Fig. 4a).
- 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 clean any micro-particles present on the side of the palette (Fig. 4b).
- 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, due to the decompression of the support spring (Fig. 4c).
- 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. 4d).

b. ROBOT

For the components transport and the assembly needs of our prototype we have developed a small 4 degrees of freedom robot similar to a SCARA robot (x, y, z, and θz) as it is shown in the **Fig. 5**. It is also possible to integrate any other compact robot like a small delta robot [5]. It executes assembly and conveying tasks or can collaborate with a high precision robot for more precise assembly. It transfers parts inside each microbox and from one microbox to the next one. Moreover it is used to open the entry port as explained previously. It operates in the cleanroom environment class ISO4. Its workspace is a cylinder of 130 mm diameter and 20 mm height. The robot itself has a size of 100x100x200 mm.

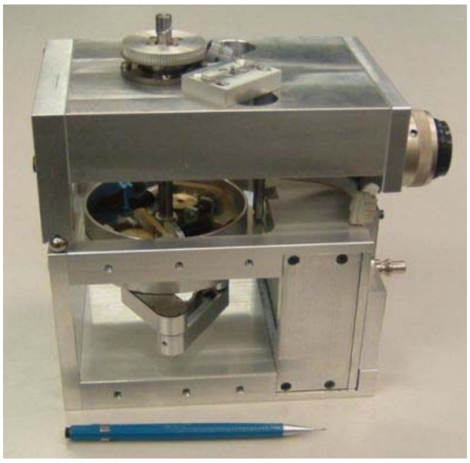

Fig. 5: The 4 DOF robot associated with a microbox

The actuators of the robot are situated in a cylindrical base, outside of the clean area. If necessary it is possible to take the robot out easily for maintenance. The pick and place of the components is performed using vacuum.

c. CLEAN AIR LAMINAR FLOW SYSTEM

This part is the heart of the clean air environment system. The goal was to use a very compact filtrating system. As explained below, 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]:

$$\frac{Q_m}{A}=\frac{\Delta P}{\beta \cdot e} \Rightarrow Q_m=\frac{A \cdot \Delta P}{\beta \cdot e}$$

Where: Q_m is the flow rate, A is the surface unit, ΔP is the pressure drop, 1/β is the permeability of the filter and e is the filter thickness.

The HEPA filters have low permeability (1/ β) to increase their filtering efficiency. In order to reduce the pressure drop necessary for the filter, these filters must 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 (e), as shown in the Fig.6.

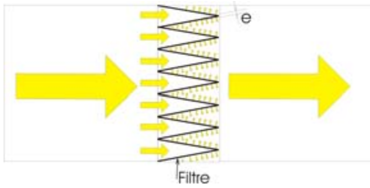

Fig. 6: Dimensions of an HEPA filter

The pressure drop that an axial ventilator can offer for a flow rate of $18m^3/h$ 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.

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 use compressed air and appropriate filters. The resulting pressure drop is about 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.

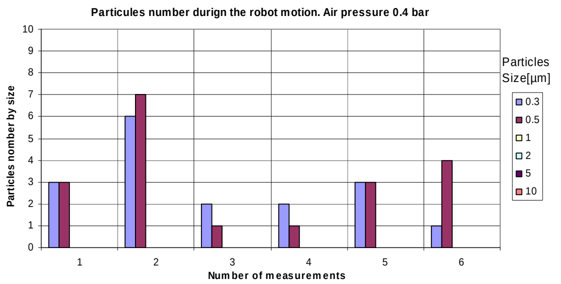

Fig. 7: Particles number in function of time

The small volume of the working area and the laminar flow of the clean air allow achieving a cleanliness class 10 in less than 2 minutes. Fig. 7 shows the measurements during the robot motion. The duration time of each measurement is about one minute. We have represented the number of each size particles present on the air in the Pocket-Factory. All these measurements were realized in a normal, non-clean laboratory. To establish the clean environment, we used the compressed air, filtered only by the Pocket-Factory filter.

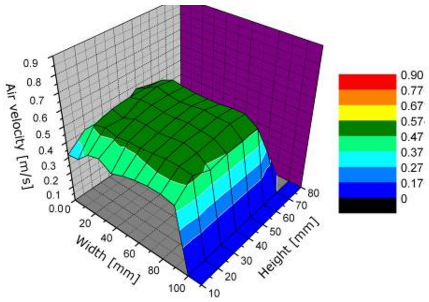

Fig. 8: Air velocity measured 15mm after the laminator

The compressed and filtered air passes through a 30 mm thickness laminator and becomes laminar. Fig. 8 shows that the air velocity measured at a distance of 15mm from the laminator is homogeneous. The average velocity is 0.52 m/s with a standard deviation of 0.024 m/s.

In a clean room it is essential to get laminar flow to guarantee that all the generated particles are guided outside of the room. 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 visualize the air flow. For better visualization, we illuminate the smoke with a red laser light. In Fig. 9 we see a top view of the result of this experiment in front of the laminator where the flow is laminar.


Fig. 9: This experiment shows the laminar flow inside the microbox

V. Methodology for the Conception of the Microfactoy

A dedicated methodology has been developed to find the best configuration for a Pocket-Factory. The assembly of each component is executed in a separated microbox. Depending on the needs of the assembly operation of the component, each microbox can harbor one or more machines (insertion, gluing, curing, high precision manipulation, etc).

Some factors that determine the size of the Pocket-Factory are the size of the components to assemble, the robots and the machines that are necessary for the assembly, their cycle time, dimension and cost.

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 for the components transfer to the palette. 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 exists an optimal configuration of the Pocket-Factory. In Fig. 10 we can observe the influence of the size of the palette (here in inches) to the assembly time for a given component.

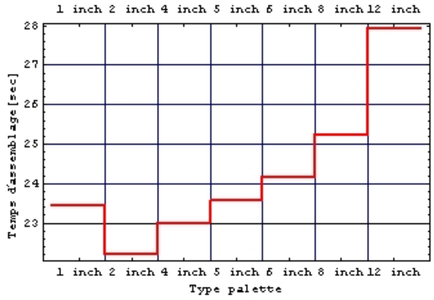

Fig. 10: Assembly time as function of the size of the palettes.

To establish all the possibilities a program written in Borland Builder C++ 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 in Fig. 11.

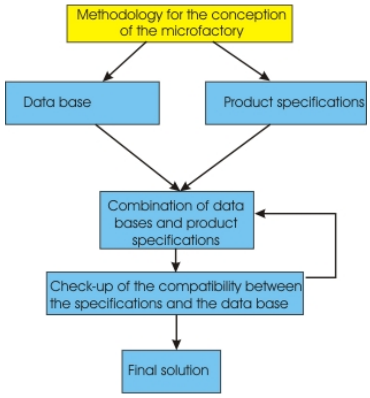

Fig. 11: Flow chart for the methodology of conception for the microfactory

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

In the second part the user must introduce 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. 12.

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.

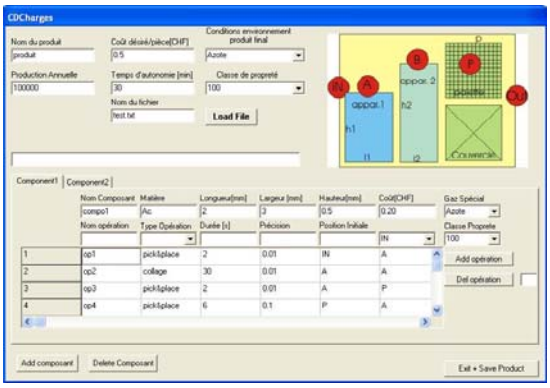

Fig. 12: Window for the registration of the product characteristics

In the final part the user controls once more the compatibility of the choices for each microbox and if the time to produce for one microbox is less than the double of the others, he can double this microbox to increase the global throughput of the Pocket-Factory.

VI. 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 including 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 4, it is less than two minutes even during robot motion.

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

Acknowledgment

This work is done in collaboration between the Ecole Polytechnique Fédérale de Lausanne (EPFL) and the Centre Suisse d'Electronique et Microtechnique (CSEM) who finances this project. Their support is gratefully acknowledged

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