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Efficiency evaluation of micro factory for micro pump manufacture†

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Abstract

The micro factory, a miniature manufacturing system, is a means of achieving higher throughput with minimal space, and minimal consumption of energy and resources by downsizing of production processes. Even though, a micro factory is able to perform whole manufacturing processes like the macro factory, the possibility of improving its manufacturing efficiency has not been considered enough. In this paper, an efficiency index is proposed to calculate the efficiency of the micro factory to manufacture a micro pump. The efficiency index has been proposed based on efficiency definition with input and output parameters of the system. Input parameters include cost of system, processing time and energy. Output parameters represent number of product manufactured from the microfactory. Cost of the system has been categorized by micro assembly machine cost, cost of resources, manipulators' cost, manufacturing space value, and human operators. Processing time has been categorized by assembly time and material handling time.

Keywords: Efficiency Index; Input Parameters; Microfactory; Micro Product; Micro Pump

1. Introduction

The term "micro factory" refers to a small-sized production system dedicated for the manufacture of small parts (micro~millimeters in size) requiring high-precision, high throughput and low production cost. Miniaturization of machine tool leads to enormous savings in energy, space, time and resources. With the high degree of current micro-fabrication technology, researches aiming at the materialization of micro machines are actively carried out worldwide [1-3]. The term "micro factory" was initially proposed by the Mechanical Engineering Laboratory (MEL) in Tsukuba, Japan in 1990 for their small manufacturing and assembly system. In 1999, AIST developed the first prototype of a micro factory that performs a series of fabrication and assembly on a desktop [4-6].

The micro factory has considerable capability of micro mechanical fabrication. To date, many other micro factories have been proposed. In today's hyper-competitive environment, manufacturing organizations are continually searching for development and fund projects that will reduce manufacturing cost and increase productivity. Even though the microfactory is able to perform the entire manufacturing process like the macro factory, the possibility of the micro factory is to improve its manufacturing efficiency for manufacturing of micro parts has not been considered enough. In 2006, AIST Japan proposed an efficiency index to calculate the efficiency of a manufacturing process based on the time required for each manufacturing process with an example of miniature ball bearing assembly [7]. In this paper, the micro pump assembly taken as an example and an efficiency index is proposed to calculate the efficiency of the micro factory by considering time, cost and energy required for

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the manufacturing process.

2. System overview

The micro factory has considerable capability to fabricate micro mechanical product. To date, many other micro factories have been proposed. In today's hyper-competitive environment, manufacturing organizations are continually searching for development and fund projects that will reduce manufacturing cost and increase the productivity. In the micro factory, the system is designed to produce small products or parts (micro~millimeters in size) requiring high precision, high throughput and low production cost. The miniaturized machine tool is expected to have a significant reduction of energy consumption for machine drive, space and resource by replacing the conventional manufacturing system. Due to small size flexibility in designing the system layout, flexibility for varieties of product, increase of speed and positioning accuracy due to decrease of inertial forces, it reduces emissions to the atmosphere. In this section the applied system, its layout, processes involved and the example product used have been discussed.

2.1 Example product (micro pump)

As we mentioned earlier, Micro pump assembly is taken as an example product. Fig. 1 shows the parts of the micro pump fabricated by the micro factory to show its capability. It has been divided into three major parts upper plate, metal thin film and lower plate. The product upper plate includes chamber and piezo electric thin film as shown in the figure. The product lower plate has inlet and outlet valve/port.

These parts are fabricated by the micro machine and assembled by the micro assembly machine in the micro factory. The processes involved and machine tools used to fabricate the micro pump are explained in the subsequent section.

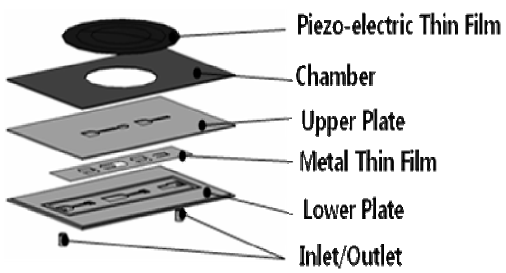

Fig. 1. Micro pump.

2.2 System layout and process sequence

Shown in Fig. 2 is the 3D model of our micro factory system to manufacture a micro pump assembly. It has micro press, micro milling machine, EDM machine, assembly machine, and robot arm. The two-dimensional layout of the system is shown in Fig. 3. Here we have two input terminals: one is the input of aluminum metal thin film and another one is the upper and lower plate of the micro pump. The process sequence is explained in the Fig. 4: at one end the aluminum metal thin film has been inputted into the micro press for pressing operation. After the pressing operation on the top surface of the metal thin film by the micro press, it has been twisted to its other side using the twisting machine and located into the EDM machine for the machining operation of the bottom surface.

In the EDM machine the bottom surface of the metal thin film has been machined and transferred into the assembly machine by a robot arm. At the other end,

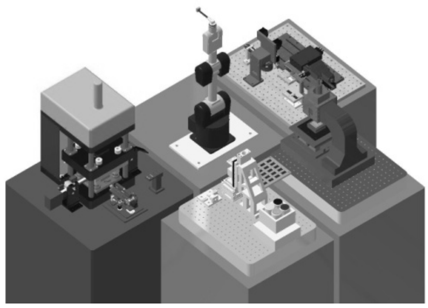

Fig. 2. Layout of the system (3D).

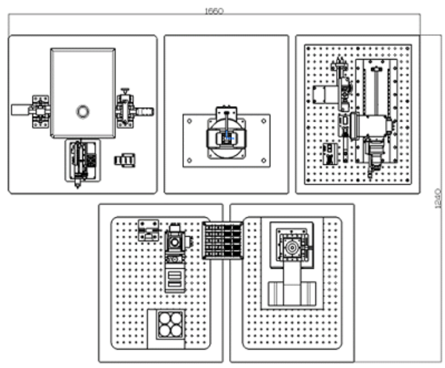

Fig. 3. Layout of the system (2D).

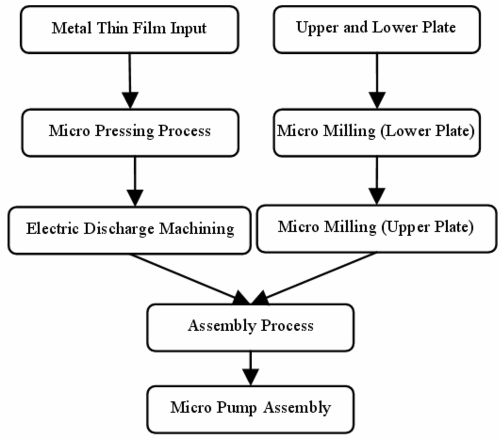

Fig. 4. Process sequence.

the upper plate is loaded into the micro milling machine for machining the surface, where the milling operation is performed over the surface of the upper plate and transferred into the assembly machine by robot arm. Next, the lower plate is loaded into the micro milling machine and milling operation is performed over the surface of the lower plate and transferred into the assembly machine by the robot arm. In the assembly machine upper plate, the lower plate and metal thin film have been assembled as a micro pump.

3. Efficiency index proposal

Here we define the coefficient to evaluate the efficiency of the micro factory to manufacture micro pump. The efficiency index (Emf) has been proposed based on the basic efficiency definition with the input and output parameter ratio, and it is represented mathematically as Eq. (1).

Microfactory Efficiency Index = [Output / Input]
Here,
Output = Number of products manufactured
Input = [Cost of the system * Time required to Manufacture * Energy required to Manufacture]
Emf = [Np / (Cs * Tm * Em)] (1)

Here (Np) is the output and refers to the number of products produced/fabricated from the micro factory, (Cs) is the total cost of the production system, (Tm) is the total time required to fabricate/assemble the example product, (Em) is the energy, is the environment impact; here we are considering it as total energy/power required to produce the product. Each parameter has been included with categories; the upcoming sections will discuss about the parameter categorization used for the proposal.

Table 1. Cost of the system.

Micro Machines	Cost in Million Won
Mill	25
Press	30
EDM	25
Robot	16
Assembly Machine	20

Table 2. Time required for each process per unit.

Micro Machines	Time required
Mill	10 min
Press	31 sec
EDM	5 min
Robot	24.721 sec
Assembly Machine	5 min

3.1 Input parameters

Input parameters include cost of the system, processing time and energy. Cost of the system (Cs) has been divided into many categories such as cost of the assembly machine which is used to assemble the micro parts as an micro assembly, cost of manufacturing machine which includes cost of the micro press and micro milling machine, cost of the resources, cost of the manipulators, cost of the manufacturing space and cost of the human operators. Processing time (Tm) includes the time required to manufacture, material handling and assembly process time. Finally, the energy required (Em) to operate the system for making the micro assembly.

3.1.1 Cost categorization

Generally, the cost of the system represents the investment for the production; as we mentioned above, the cost of the system has been divided into many categories. The machines listed and the rough estimated cost of machines used in the micro factory has been tabulated in Table 1 and it has been represented in million won. The total cost of the micro system has been estimated as 116 million won. In addition, the operator's cost was assumed to be 2 million won and the manufacturing space used to adopt our micro factory is 500 x 600 x 860 centimeters; the value of the space has been assumed as 8 million won. As per the Nozomu Mishima (AIST, Japan) efficiency index proposal [7], the micro factory which is to manufacture the miniature ball bearing assembly was approximately about 12 million yen and the conventional system used to manufacture the same micro product was approximately about 600 million yen. From this we can find that the cost ratio between the conventional and micro system to manufacture the miniature ball bearing assembly was about 50. By assuming the same cost ratio to our system to manufacture a micro pump, we can forecast that the cost of our micro system is smaller than that of the conventional system.

3.1.2 Time categorization

Total time required to produce the assembly has been categorized by scheduled and non-scheduled time. Scheduled time includes process time and handling time; non-scheduled time includes system initialization, modification, shut down and start-up time. Here we are focusing on scheduled timings. In the scheduled timings the process time includes the assembly time required by the assembly machine to do the assembly process, processing time required to do the milling process, pressing and machining process by the micro milling machine, micro press and EDM machine. The handling time includes the transfer time, loading/unloading time, and alignment time. These time data required to calculate our efficiency value was measured from the simulation of the system with the resources and tabulated in Table 2.

3.1.3 Energy categorization

Energy is the power required to operate the machine tools in the micro factory. Each machine tool in the system has built-in servo motors with the peak current of 1.13 ampere, peak voltage of 80 and 40 ~ 70 W powered motors. Here we are considering the lowest power of the servo motor for our efficiency calculation in terms of Kilo Watts (KW). The total energy required to do the processes has been calculated by multiplying the power of the motor and the total time required to do the processes.

3.2 Output parameters

The output parameter refers to the number of products manufactured/assembled from the system at a particular span of time and it is represented as throughput in the efficiency index.

4. Result

By applying the parameters value of the micro factory into the efficiency equation (Eq. 1), we are calculating the value of micro factory efficiency for single micro pump manufacturing. The cost of the system represents the cumulative cost of the machine tools; from Table 1 we can take the cost of the system is 116 million won, and operator cost and the manufacturing space value is 10 million won. The total energy required to manufacture a micro pump has been calculated by multiplying the power of the motor and the total time required to do the processes in the calculation. From Table 2, the time required to manufacture a micro pump has been calculated as 20 minutes and 53.32 seconds, which is converted to 20.88 minutes for calculation. By applying these values into the equation, we obtain the efficiency index for our micro factory as 0.0095.

$$Emf = Output/Input = [Np / (Cs * Tm * Em)]$$
$$= [1 / (126 * 20.88 * 0.04)] = 0.0095$$

As we mentioned earlier, the Nozomu Mishima (AIST, Japan) efficiency index proposal [7] to manufacture the miniature ball bearing assembly was approximately about 12 million yen and the conventional system used to manufacture the same micro product was approximately about 600 million yen. The cost ratio between the conventional and micro system to manufacture the miniature ball bearing assembly was about 50. By assuming the same cost ratio to our system to manufacture a micro pump, we can forecast that the cost of our micro system is smaller than that of the conventional system. The initial investment for the conventional system to manufacture our micro product is higher than the total cost of our micro system, and the energy required by the conventional system to manufacture the micro pump would be larger than the micro factory. If we consider the proposed efficiency equation with the value of the conventional system to manufacture a micro pump, the efficiency value would be much lower than the value mentioned above and the effectiveness of the system would be lower. The final objective of this research is to prove that a micro factory-like system is capable to produce the micro products, like a conventional manufacturing system with minimal initial investment and energy. This system would be suitable, when the need arises for frequent changes in the system layout and flexibility in product design with low production rate.

5. Conclusions

In this paper, an efficiency index to calculate the efficiency of the micro factory and the criteria needing to be considered while calculating the efficiency of the system has been discussed. The system criteria include cost of the system, energy consumed by the system, time utilized to manufacture the products and number of product manufactured by the system. The final objective of this research is to prove that a micro factory-like system is capable to produce micro products, like a conventional manufacturing system with minimal initial investment and energy. This system would be suitable when there is a need for frequent changes in the system layout and flexibility in product design with low production rate. Therefore, the microfactory has a possibility as a future manufacturing system for micro mechanical fabrication of many varieties of products.

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