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A Simulation Study on the Layout Design of Micro Assembly Line for Lens Module

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Abstract: Phone-camera lens module is composed of several components which are assembled together with a given sequence. Assembly processes are conducted in an assembly line which could be a manual type or automatic type. There have been many types of automated assembly system for lens module assembly to enhance the productivity and save the labor cost. Micro assembly system introduced in this paper is another automated system having the merits of space saving and flexibility. The micro assembly line is constructed with several micro assembly machines, numbers of conveyors and a mini-crane for material handling. To compare the productivity of the micro assembly line, three layout types of rotary table with different assembly process were designed, and they are evaluated using simulation.

Keywords: Simulation, Lens module, Micro assembly line, Design, Tray layout

1. INTRODUCTION

The worldwide annual demand of mobile phone is estimated to 1.88 billion (Gartner, 2013) and it has been increased gradually. Furthermore, most of mobile phones equip one or two phone-camera lens modules (we call it as lens module). Thus, the demand of lens module increases tremendously. As shown in Fig.1, a lens module is generally composed of multiple parts, which are barrel, shield, lens and spacer. In the case of a 1.3 mega-pixel lens module, one barrel, three lenses, two spacers and one shield are assembled together. On the other hand, for the 5 or 8 or 13 mega-pixel lens modules, one barrel, four lenses, three spacers and one shield are assembled in the lens module assembly process.

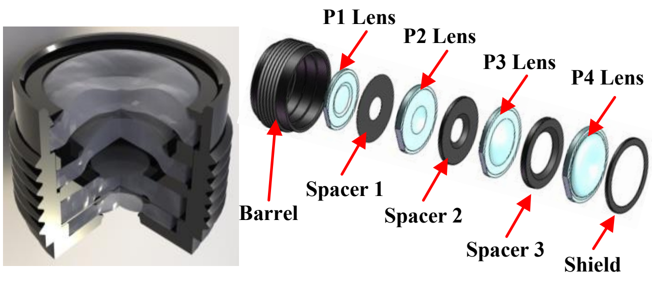

Fig. 1 Sample of lens module and its structure

All assembly tasks are processed manually in the phase of pilot production. After that, an automated assembly line is developed to increase the productivity and reduce the labour cost. The various types of automated assembly systems for lens modules were introduced in the previous works (Moon et al. 2006, 2007, 2009). However, we should note that the assembly processes requires a special manufacturing environment like clean room, and the cost for installing clean room is expensive. Thus, the needs of micro machine and micro factory were raised.

The concept of "micro factory" was proposed by the Mechanical Engineering Laboratory (MEL) of Japan in 1990. It refers to a small-sized production system suitable for fabricating small-sized products (Tanaka, 2001). The major merits of micro factory are to save great amount of resources like space, energy, materials and time (Yuichi et al., 2004).

There have been various types of micro machine to assemble micro product. Rotary table is one of the popular devices that applied to micro assembly machine. Gilbert and Quick (1986) described how to predict the performance of an automatic assembly machine of the rotary table indexing type. Kobel and Clavel (2011) introduced the design of micro robot equipped in rotary desktop assembly line in a clean room, and the assembly machine introduced in their paper has similar concept with our machine, but they did not mention about the design of assembly line.

VM (Virtual Manufacturing) is very powerful technology for developing a new machine or designing a new manufacturing system, and it is an integrated computer-based model which represents the physical and logical schema and the behaviour of a real manufacturing system (Iwata et al., 1997 and Lee and Noh, 1997). The core technology of VM is simulation, and two types of simulations, mechanical simulation and discrete event simulation, are widely used in VM.

In this paper, a discrete event simulation for designing the micro assembly system is introduced in which phone-camera lens module is produced. The performances of three types of micro assembly line are compared by simulation experiments. In section 2, production processes of lens module and system configurations are explained. The simulation models, their control logics and simulation results are described in section 3, and it is followed by conclusion in section 4.

2. LENS MODULE ASSEMBLY SYSTEM

2.1 Lens Module Assembly Processes

The manufacturing processes of a lens module are composed with a lens line for producing lens unit, and a lens module line which includes a lens module assembly line and its downstream processes as shown in Fig.2. As the main part of lens module, unit lenses are produced by the injection operation. Through the gate cutting operation, the lenses are coated in a coating machine. After the inspection is finished, the lenses are transferred to the lens module assembly line. Different types of parts such as barrel, lens, spacer and shield are prepositioned in their own tray for assembly. The number of parts in a tray depends on the sizes of tray and part types (for example, from 64 to 121 units).

The trays are transferred to the assembly line for supplying the assembly parts. As we can see from the Fig.2, a barrel is loaded in the assembly machine first, and then P1 lens is inserted into the barrel. And then, three additional lenses, three spacers and a shield are stacked into the barrel sequentially. After UV bonding and curing process, the finished lens module will be unloaded from the lens module assembly line. Finally, the lens modules go through the inspection machine for verifying and the qualified units will be marked with a series of number with the laser marking machine. However, this paper focuses on the lens module assembly processes excluding UV bonding and curing process.

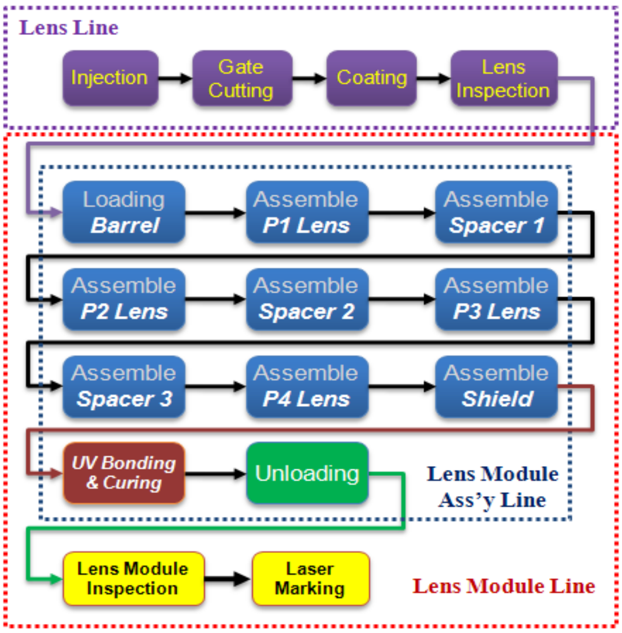

Fig. 2 Manufacture processes for lens module

The micro assembly line consists with several micro assembly machines described in section 2.2 and a mini-crane. The role of mini-crane is to unloading and loading trays and transfer trays.

2.2 Configuration of Micro Machine

The core component of micro assembly line is the micro assembly machine. Fig.3 shows the 3D model of the micro assembly machine. The main components of this micro-assembly machine include four devices, which are rotary table containing eight trays, assembly pickers, punching rod and linear motor for moving pickers. Fig.4 shows the structure of these three parts. Various types of trays are located on the rotary table, and the table rotates in bi-direction. The motion of punching rod is simply up and down, and it presses part for tight assembly, whenever a new part is stacked.

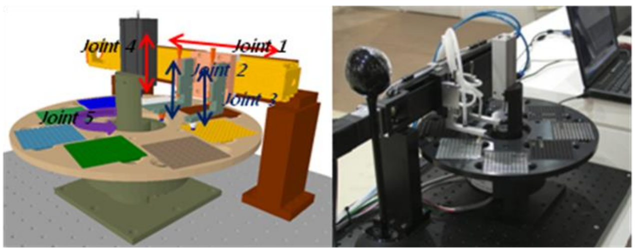

Fig. 3 3D model and real micro assembly machine

There are two types of assembly pickers as shown in Fig.4. Picker 1 is used for handling lenses and assembled module, and picker 2 is used for handling barrel, spacer and shield. The linear motor enables pickers to move between trays and assembly position (the centre of rotary table).

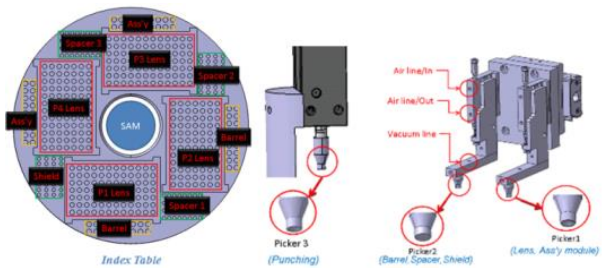

Fig. 4 Main components of micro assembly machine

2.3 Layout Types of Trays

Three types of the layout concepts how to assign trays are considered, and they are called as the layout type A, layout type B and layout type C respectively. Note that eight trays are available on the rotary table.

As shown in Fig. 5, layout type A is designed for one-machine cell. It means that all parts are located on a table and all assembly processes are completed one machine. However, two parts (P3 lens and P4 lens) should be contained in a tray because the available spaces for trays are eight. Thus, if we install more than one machine, this system is a traditional parallel system and the remaining problem is how many assembly machines are supported by a mini crane.

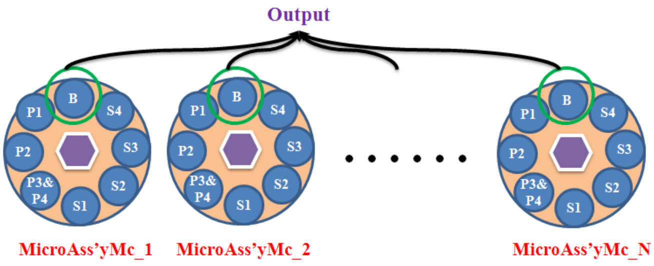

Fig. 5 Layout of trays in type A

The layout type B is designed for three-machine cell. It means that three micro assembly machines corporate together during the total assembly process. As shown in Fig. 6, the layouts of M/C 1 and M/C 3 are same, and each machine contains the trays of barrel, P1 lens, P2 lens, P3 lens, Spacer 1 (S1), Spacer 2 (S2), Spacer 3 (S3) and sub-assembly (Sub1or Sub 2). The micro machine in the middle position (M/C 2) is the final assembly machine in which the subassemblies (Sub 1 or Sub 2) coming from M/C 1 and M/c 3 are assembled with P4 lens and Shield (S4). The final assembly products (lens modules) are put into F1 (or F2) tray and they are unloaded and go out of the machine the tray is full. Fig.7 shows us a detailed description of the assembly process for each machine.

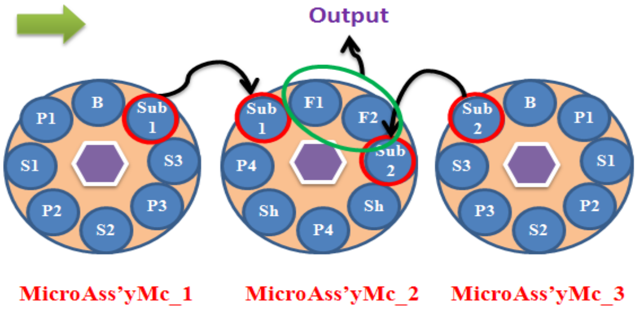

Fig.6 Layout of trays in type B

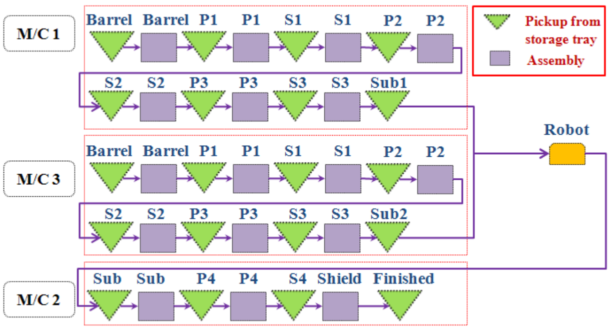

Fig.7 Assembly process for type B

The layout type C is designed for four-machine cell. It means that four micro assembly machines are assigned to conduct all assembly processes as shown in Fig. 8 and 9. In M/C 1, the barrel, P1 lens and S1 are assembled. The sub-assembly (sub 1 or sub 2) of M/C 1 is transferred to M/C 2 by the mini-crane (moving robot). In M/C 2, the sub 1 (or sub 2) will be assembled with P2 lens and S2. Then the product of M/C 2, which are sub 3(or Sub 4), is transferred to M/C 3. In M/C 3, the sub 3(or Sub 4) is assembled with P3 lens and S3. The sub-assembly is put on the trays of Sub 5 (or Sub 6). Finally, P4 lens and S4 are assembled with Sub 5 in M/C 4 and the final products are put on the tray (F) for unloading.

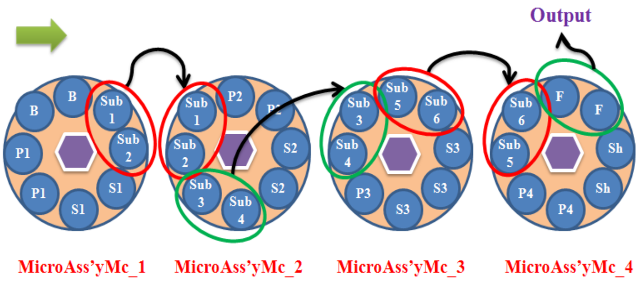

Fig.8 Layout of trays in type C

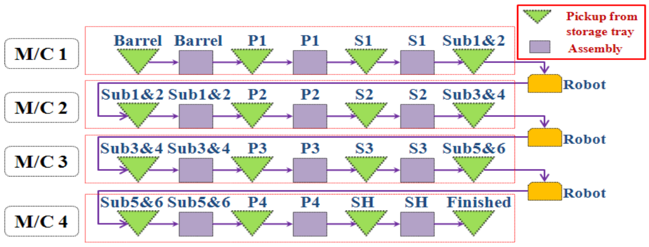

Fig.9 Assembly process for type C

2.4 *Configuration of Assembly Line*

With these three types of tray-layouts, we designed three different lens module assembly lines, one-machine cell (type A), three-machine cell (type B) and four-machine cell (type C). In type A, the machine should be stop during the time between unloading finished tray and loading a new tray which includes a moving time of mini-crane. On the contrary, in type C, the machine should be stop during unloading and loading time, because there is spare tray containing same part.

Fig. 10 shows the structure of the assembly line of type A. Assembly lines of type B and C are different in that layouts of trays in micro machines are different. The assembly line consists with a conveyor group (Conveyor_Group_S) for supplying barrel, P1 lens ~ P4 lens, and a conveyor group (Conveyor_Group_R) for recycling assembled tray and empty tray. It also has a set of vibration machine for sorting and supplying spacers and shield. There is only one mini-crane for transporting assembly parts, and finally a set of micro assembly machines are integrated.

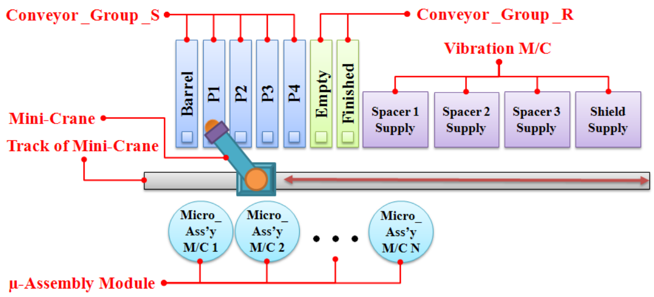

Fig.10 Structure of lens module assembly line (type A)

3. SIMULATION

3.1 Simulation Modelling

To compare the performances of three types, we assume that 12 micro machines are assigned to each type. Then, twelve one-machine cells are running in parallel in type A, four three-machine cells are parallel in type B and three four-machine cells are parallel in type C, respectively.

The discrete event simulations models are developed with QUEST® and the detailed control logics are programmed with SCL in QUEST®. Fig. 11 shows a snapshot of simulation model.

Fig.11 Snapshot of simulation model (type C)

3.2 Input Data

■ Micro-Assembly Module

The cycle time for processing a single step of assembly in each type of μ-Assembly module is different. Since the average processing time for assembling one unit of component to the lens module is about 3 second, the cycle time for initial design (type A) is 30 second (barrel + P1 + S1+ P2 + S2 + P3 + S3 + P4 + S4 + place on barrel tray). On the contrary, the cycle time for type C is 12 seconds (barrel + P1 + S1 + place on sub tray). Similarly in type B, the cycle time for assemble one unit of sub product or finished product is 24 seconds (barrel+ P1 + S1 + P2 + S2 + P3 + S3 + place on sub tray) or 12 seconds (sub product + P4 + S4 + place on finished tray).

There's no extra buffer between the assembly machines. Although there are two trays containing same parts, we pick up a part from a second tray when the first tray is empty. In a same way, sub-assembled part is stored in the second tray when the first tray is full. These rules are used for Type B and C. The MTTF (Mean Time to Failure) and MTTR (Mean Time to Repair) are estimated from the historical data of similar machine, and time dependent failures are assumed. Table 1 shows the failure rate and repair rate of the micro assembly machine.

Table 1. Failure and repair rate of assembly module

	MTTF	MTTR
Micro ass'y M/C	Expo(1800)	TRIA(120,180, 240)

■ Mini-Crane

Only one mini-crane moves along with a straight track with by-direction. The operation parameters of the mini-crane are shown in Table 2.

Table 2. Operation parameters of the mini-crane

Speed	Loading	Unloading	Ac	Dc
550 mm/s	4 sec	5 sec	5000 mm/s	5000 mm/s

The assembly machine stops during the process of loading and unloading. Thus, when the mini-crane received a signal for parts requirement, it must wait until the assembly machine finishing one cycle. Table.3 shows the failure rate and repair rate of the mini-crane.

Table 3. Failure and repair rate of the mini-crane

	MTTF	MTTR
Mini- Crane	Expo(3600)	TRIA(120,240, 480)

■ Vibration Machine

Since this paper only considers about the effect of the lens assembly module, we assume that the supply of spacers and shields are sufficient.

■ Conveyor

The *Conveyer_Group_S* supply of barrels and lenses are also supposed to be sufficient and the conveyors performing as buffer's function that there're always five trays are stored in each conveyor. The *Conveyer_Group_R* is responsible for recycling the empty tray and the tray containing finished parts. We assume that it has no effect on the total performance of the system.

■ Trays

Ten types of trays are use in the system. The external dimension for all the trays are same, but the size of assembly components are various from type to type. Thus, the capacities of different types of trays are different. The capacities of each type of trays are listed in Table 4. In P3 and P4 lenses, the numbers in parentheses are tray capacities in type A.

Table 4. Capacities of each type of trays

Tray	Capacity	Tray	Capacity
Barrel	64	Spacer 1	121
P1 lens	121	Spacer 2	121
P2 lens	121	Spacer 3	121
P3 lens	121(60)	Shield	100
P4 lens	100(60)	Sub/Finished	64

3.3 Control Logic

The basic logics used for controlling three types of system simulation are almost same, but a special logic for transferring sub-assembly between machines is required in type B and type C. Fig.12 and 13 show examples of the basic logic for the system operation and transfer logic for sub-assembly, respectively.

■ **Basic Control Logic**

Step1. If a new barrel tray arrivals at the buffer which entitled with *Barrel Supply*, the buffer will check the status of the *mini-crane* to see whether it's idle or not. At the same time, it checks the two barrel tray in rotary table to see whether they are empty or not (See line 1).

Step2. In case that any of the two barrel tray is empty, a signal defined by user (1000) is sent by the *Barrel Supply* buffer to the *Empty Tray Source*, and an empty barrel tray will be created (See line 2).

Step3. The *Empty Tray Source* checks the *Out Buffer* whether it is empty or not. If it is empty, the part of empty barrel tray waits for sending to the *Out Buffer* (See line 3).

Step4. If the *mini-crane* is idle, the empty barrel tray is sent to the *Out Buffer* and taken away by the *mini-crane*. Otherwise, it waits in there (See line 4).

Step5. When the empty barrel tray arrives at the *Empty Tray Out* (a buffer linked with sink), the *Empty Tray Out* sends a signal defined (i.e., 1001) to the *Barrel Supply* according to the different part types.

Step6. The new barrel tray will go out of the buffer and be transferred to the *In Buffer* by *mini-crane*. From the *In Buffer*, it enters to the micro-assembly machine.

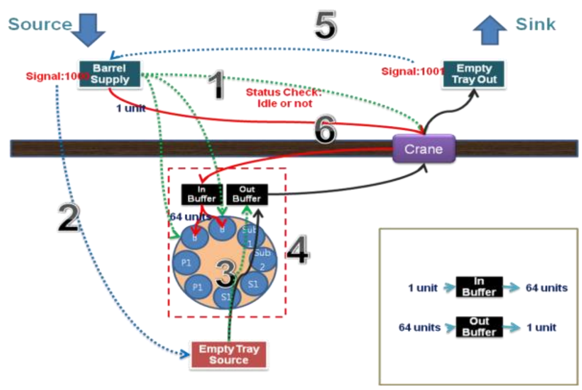

Fig.12 An example of basic logic

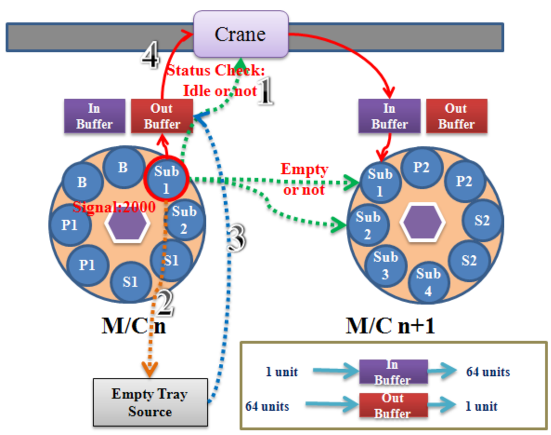

Fig.13 Logic for sub product transportation

■ **Transfer Logic**

Step1. The sub tray buffer checks the status of the mini-crane. At the same time, it checks the *Sub 1* tray & *Sub 2* trays in the next station. If one of them is empty, go to step 2. Otherwise wait until one of them is empty.

Step2. *Sub 1* tray (for example sub 1 is full) sends a signal of 2000 to the *Empty Tray Source*.

Step3. The *Empty Tray Source* checks whether the *Out buffer* is empty or not. If empty, then go to Step 4. Otherwise, wait until it becomes empty.

Step4: The *Sub 1* tray enters to the *Out Buffer* and then be picked up by *mini-crane*. The *mini-crane* carry the sub 1 tray to the next station and put it into the *In Buffer* from where it enters the assembly module.

3.4 Experiments and Results

To compare the throughput of three types of assembly systems, we conducted simulation experiments. The simulation run time is set to 2304,000 seconds, including 230,400 seconds for the warm-up period. Thus, the data collection time is 2,073,600 seconds. For each scenario, 10 replications are conducted and the average values are calculated. Table 5 shows the performance measures of each system. The total throughput of type A is the biggest, and that of type C is the smallest.

Table 5. Results of simulations

	Type A	Type B	Type C
Throughput (Tray)	8,946	7,077	5,489
Throughput (EA)	572,544	452,928	351,296
Quantity per MC(EA)	47,712	37,744	29,275
Takt time[1)] (Sec)	3.62	4.58	5.90
Utilization of crane (%)	79.37	72.29	63.02

[1)]Takt time = 2,073,600/Throughput(EA)

Table 6 is the detail portion of the state of mini-crane. In type C, the blocking probability is higher than the others. We guess that it is the major reason of low productivity in type C, and it is due to assumption that the request for mini-crane follows FCFS.

Table 6. Portion of mini-crane's state (%)

States		Type A	Type B	Type C
Busy	Loading	20.2	19.0	18.5
	Unloading	25.2	23.7	23.1
	Loaded Travel	17.5	14.5	10.8
	Empty Travel	16.5	15.1	10.7
	Sub-total	79.4	72.3	63.0
Idle		3.6	4.5	0.1
Blocked		11.9	17.3	30.0
Failed		5.1	5.9	6.9
Total		100.0	100.0	100.0

In type C, a micro machine can continue assembling operations even when the mini-crane moves to the conveyors or vibration machines for release the tray or picking up a new tray, because two trays containing same part are assigned in a rotary table. On the contrary, in type A (or B), the machine should stop assembly processing during the tray exchange time including transportation time of mini-crane. Thus, sensitivity analysis was carried with respect to the mini-crane speed, and the result is in Fig. 14. The speed of mini-crane is decreased gradually, 80%, 60%, 40% and 20% of original speed (100%). As a result, the gaps among three types are reduced gradually.

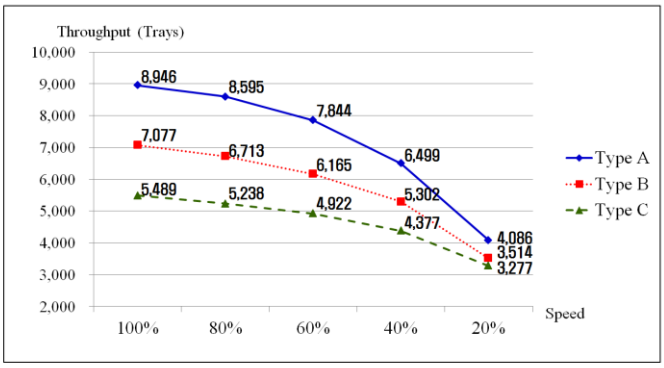

Fig.14 Sensitivity analysis of mini-crane speed

4. CONCLUSION

In this paper, we introduce a micro machine used for assembling phone-camera lens module. Three types of micro assembly cells composed of 12 micro machines and one mini-crane are suggested. Three types of tray layouts are implemented to three different assembly cells.

Simulation results indicate that the throughput of type A is the best and that of type C is the worst. There is no problem when one mini-crane serves 12 micro machines. From the sensitivity analysis, we conclude that the gap of throughput between type A and type C is reduced as the decrease of mini-crane speed.

For further research, some dispatching rules which reduce the blocking probability should be developed for type C. The new dispatching rule may increase the throughput of type C.

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