Development of desktop machining microfactory

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The Mechanical Engineering Laboratory developed a prototype desktop machining microfactory. The microfactory, which will enable considerable savings in terms of energy, space, and resources, is a downsized production system whose size is very small with respect to the dimensions of the products. The desktop microfactory consists of machine tools such as a microlathe, a milling machine, a press machine, and assembly machines such as a transfer arm and a two-fingered hand. The microfactory can produce miniature machine parts and assemble them as well as an example of an application, a miniature bearing assembly is produced successfully.

Introduction

Microfabrication technologies have been steadily advancing in recent times. Research and development are being vigorously conducted with a view toward the implementation of micromachines. The use of micromachines is likely to increase, and they will become more closely related to our daily lives. Various small-sized products such as compact-sized watches and office automation equipment as well as micromachines will be increasingly enhanced. In line with the requirements of such improvements, manufacturing facilities and production systems will tend to be larger in size. In marked contrast to such a trend toward the increased use of large-sized facilities and systems, the Mechanical Engineering Laboratory (MEL) proposed the concept of a "microfactory" in 1990. This term refers to a small-size production system suitable for fabricating small-sized products. A microfactory would not only provide considerable savings in terms of energy, space and resources but would also facilitate changes in the production line layout. It could change the long-established image of factories and would also enable a wide variety of production systems and various other future possibilities.

Recent progress in control and fabrication technologies of microstructures has enabled prototyping of small machines. In 1996, MEL developed a miniature lathe called the microlathe. Although the microlathe was only 1 cubic inch in size, it was capable of cutting metal more accurately than a conventional lathe with substantial energy-saving effects. The success of the microlathe was the driving force to prototype an entire machining factory, which consisted of a microlathe and various other small-sized machining tools, conveyor and assembly device, which were verified to perform a series of fabrications and assemblies on a desktop. This paper explains at first the features of microfactory, then describes the developed machining microfactory and specifications of the component devices.

Features of microfactory

The microfactory has the following features due to the extremely small size and light weight of its component devices and systems.

- Driving energies of facilities and energy required to control the environment of the system such as air conditioning and illumination decrease with decreasing size.
- Decreased inertial force due to the light weight of facilities can drive the facilities itself with promptness, high speed, and high positioning precision.
- Flexibility of manufacturing systems increases because layouts of the production system can be easily changed compared with those of conventional systems.

The possibility of creating a microfactory is realized with the recent development of micromachine technologies. The above features can be effectively implemented to formulate the following types of future production systems.[1)]

- Advanced development production system
- On-site manufacturing system for maintenance
- Prompt manufacturing system in a store, office and home for personal needs
- Manufacturing system for extreme environments such as in vacuum, microgravity and extremely high or low temperature
- Mobile manufacturing system in a car, train or ship
- Microchemical reaction plant.

Developed desktop machining microfactory

To demonstrate the realization of a microfactory, the MEL developed the machining microfactory shown in Fig. 1. The

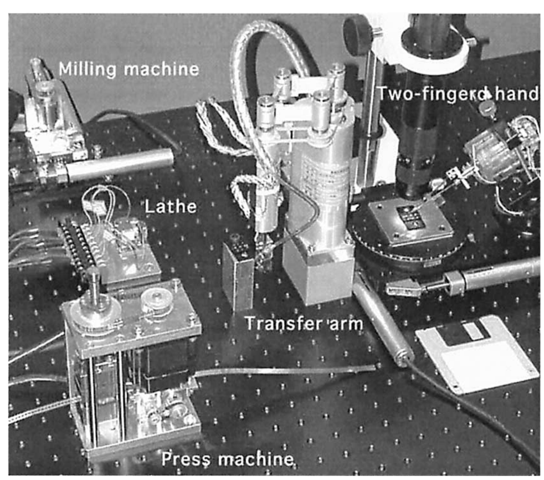

Fig. 1. Desktop machining microfactory.

factory can machine small parts on the submillimeter to millimeter order and assemble them to yield various devices. It is composed of two areas within a 500 mm × 700 mm space, *i.e.* the machining area and the assembly area. In the machining area, microparts are machined by a microlathe, micro-milling machine and micro-press machine. Machined parts are transported by a micro-transfer arm to the assembly area. Finally, a two-fingered microhand assembles the parts. Integrated production experiments are conducted to verify the precision of the microscopic component device for machining and assembly to manufacture miniature products on a desktop. The specifications of the component devices are outlined below.

Microlathe

Figure 2 shows the micro lathe. It is 32 mm long, 25 mm wide, and 30.5 mm high, and weighs about 100 g. The structure permits the main axis to move even with the tools attached.

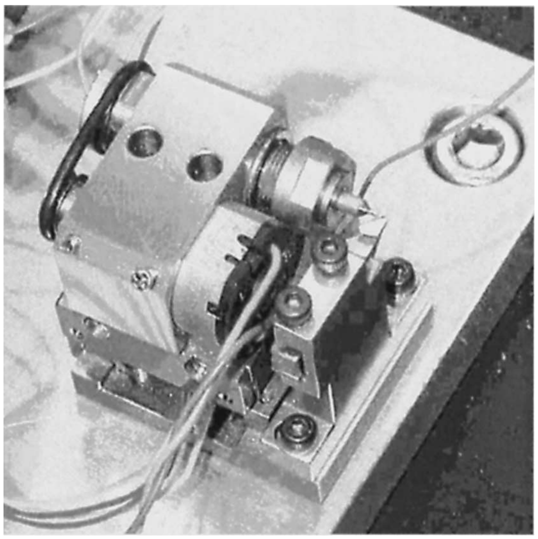

Fig. 2. Micro lathe.

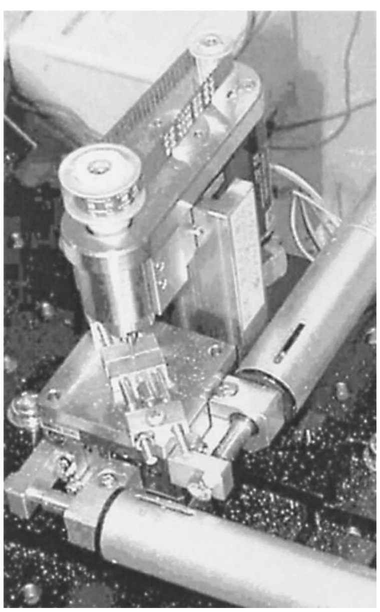

Fig. 3. Micro-milling machine.

For this purpose, a friction-driven inchworm system with a piezoelectric actuator in an X-Y stage is adopted. Although the main spindle motor has only a 1.5-W rated power, the rotating speed is about 10,000 rpm. The microlathe can cut brass with an accuracy of 1.5-μm roughness in the feed direction and 2.5-μm roundness. The minimum diameter of the work achieved in the experiment is 60 μm.[2)]

Micro-milling machine

Figure 3 shows the micro-milling machine. It is 170 mm long, 170 mm wide, and 102 mm high. It uses a brush-free DC servo motor, which has a 36-W rated power for the main spindle. The rotating speed is about 15,600 rpm. With a commercially available miniature end-mill (3-mm shank diameter) mounted on the machining section, this milling machine is capable of machining flat surfaces and drilling holes. Theoretical analyses of the machining accuracy are performed to determine the transport axis arrangement.

Micro-press machine

The micro-press machine (Fig. 4) is 111 mm long, 66 mm wide, and 170 mm high. The key to its development is the downsizing of the mechanisms according to the required press force. It has an AC servo motor with a 100-W rated power, which generates a press load of about 3 kN. The rotating motion of the servo motor is converted to a linear motion using a ball screw and a nut, which is driven *via* timing pulleys and belt. The maximum press load and press speed can be varied by changing the ratio of the teeth of the pulleys. The press machine has a micro-progressive die. It is capable of forward-feed processing with four blanking and two bending strokes. The press speed and dead point of the press stroke can be controlled numerically. It can process the top cover at a rate of 60 strokes per minute.

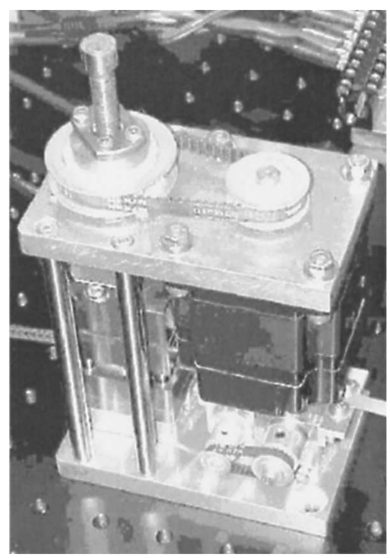

Fig. 4. Micro-press machine.

Micro-transfer arm

Figure 5 illustrates the micro-transfer arm, which is 200 mm high. It has three transitional motions of freedom and one perpendicular shaft rotation. The middle part of the arm has a pantograph mechanism of the same link length. Each joint does not have its own motor, instead, three DC servo motors

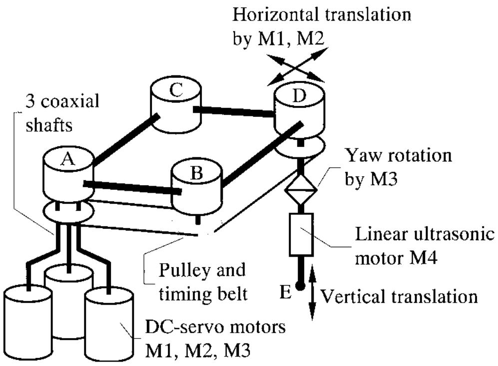

Fig. 5. Micro-transfer arm.

with a decelerator are mounted in the main body of the arm; two of them are used for rotation and expansion of the arm and the other is for rotation of the end-effector *via* timing belts. This mechanism realizes a light, compact and high-rigidity arm. The arm can work within a circle 200 mm in diameter with horizontal positional accuracy of approximately 20 μm. Although all mechanisms are compact, the arm can cover a wide operational range due to its flexible horizontal multijoint mechanism and parallel link mechanism.

Two-fingered microhand

The two-fingered microhand (Fig. 6) is shaped like a circular cylinder 48 mm in outside diameter and 65 mm in height, and has two 50-mm-long glass needle-like fingers. Each finger module has three internal piezoelectric actuators and a parallel link mechanism with elastic hinges, which can drive the finger in three transitional motions. Since the fingers can move like chopsticks, they can handle even a sticky object. The fingers can work in the range of approximately $100 \times 100 \times 30\,\mu$m. The resolution of the finger motion is 1 μm or less. The maximum controllable size of an object is 200 μm.

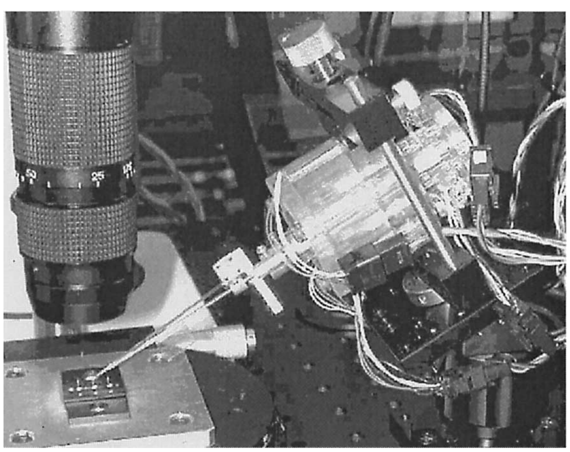

Fig. 6. Two-fingered microhand.

Trial product using the microfactory

As a trial product, the microfactory was used to fabricate a miniature ball bearing assembly with a 900-μm outside diameter and 3-mm shaft length. The bearing assembly consisted of ball bearings, a rotary shaft, a bearing housing and a top cover. The microlathe was used to manufacture the rotary shaft with a diameter tapered from 100 μm to 500 μm. The milling machine produced the bearing housing which resembles a miniature cup. Two end surfaces of the brass column of 900 μm diameter were flattened, and then holes of 200 μm and 700 μm diameter were drilled with an end mill. The press machine was used to punch out and bend the top cover of 1 mm diameter with three jaws to grasp the housing from the 120-μm metal plate. Figure 7 shows a plate punched out by a micro-press machine. All parts were transported from the machining area to the assembly area using the precision positioning transfer arm which is equipped with a negative pressure holding unit. In the assembly area, the two-fingered hand picked and inserted the seven balls of 200 μm diameter and the rotary shaft into the bearing housing. Attachment of the top cover completed the assembly. Figure 8 shows the individually fabricated parts and the assembled product.

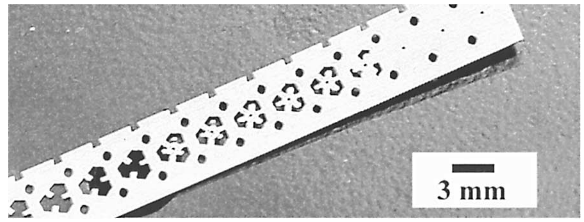

Fig. 7. Punched-out plate by micro-press machine.

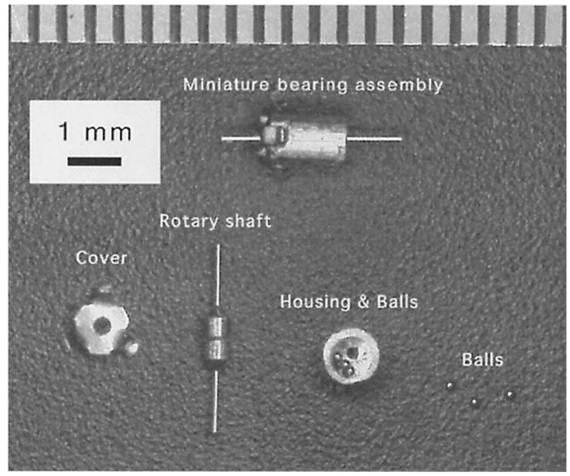

Fig. 8. Bearing assembly and parts.

Portable microfactory

The desktop machining microfactory proved the concept of space-saving machinery and assembly. A portable microfactory was designed to be packaged in a suitcase to demonstrate its portability. This portable microfactory (Fig. 9) has external dimensions of 625 mm length, 490 mm width and 380 mm height and weighs 34 kg (main body weight: 23 kg). It can also be placed in the trunk of an automobile and transported with mounted casters. It functions entirely by itself requiring a single 100 V AC power source and its power consumption

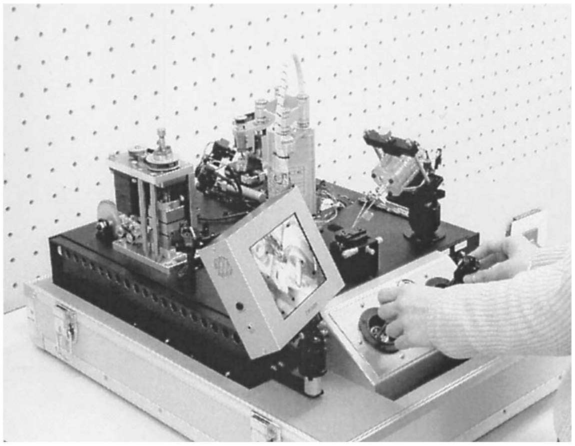

Fig. 9. Portable microfactory.

is 60 W during operation. Three miniature CCD cameras mounted on each machine tool are capable of displaying the image of a machined section on a 5.8-inch LCD monitor. Only two joysticks and one push-button are used to operate the equipment. The target device is selected with a selector and manually controlled.

Summary

Since the proposal of a microfactory nearly a decade ago and the subsequent development of the world's smallest micro-lathe, the Mechanical Engineering Laboratory has created a machining microfactory. I believe this successful realization of the microfactory concept will be a stimulus to the design of entirely new production systems in the future.

References

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2) T. Kitahara, K. Ashida, M. Tanaka, Y. Ishikawa, N. Ooyama, and Y. Nakazawa: Proc. Int. Workshop on Microfactories (1998), p. 1.