

# Pneumatically Driven Auxiliary Micro Tools For Desktop Factories

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## ABSTRACT

This paper presents the design, the simulation and the fabrication process of two novel pneumatically driven auxiliary micro tools that can be used to improve and to speed up assembling processes in desktop factories. The described micro systems are designed to function as centrifugal feeders for small glass balls or active clamping devices with small external dimensions. They are able to deliver more than six balls per second on demand to a gripper and align and clamp single chips in a fixed position.

**Keywords:** pneumatic piston, micro tool, centrifugal feeder, clamping tool, desktop factory

## 1 INTRODUCTION

The increasing miniaturization of products sets high requirements to the micro assembly process of tiny parts (e.g. micro lenses, optical fibers and bearing balls). Cost efficient and size adapted, modular production lines - also called “desktop factories” (see Fig. 1a) - become more and more popular and require handling tools in related dimensions.

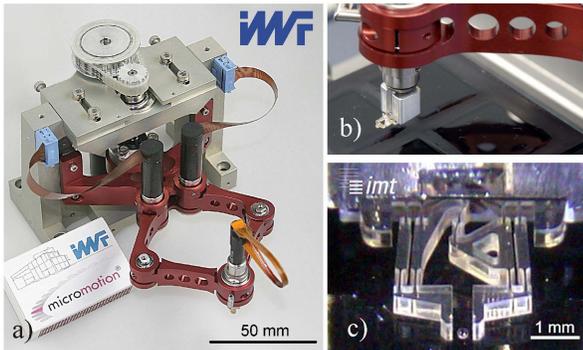


Figure 1: a) General view of the desktop-factory robot “PARVUS” (Institute of Machine Tools and Production Technology, TU Braunschweig, Germany) [1], b) robot arm with mounted micro gripper, c) gripper gearing grasping a 200 µm glass ball.

Glass balls for precision bearings, metrology styli or optical lenses usually come in tiny plastic bags or boxes and need to be manually prepared for further usage. A continuative machining with Pick-and-Place robots requires a well known position for each ball, which can be achieved by camera controlled robot systems or extensively prepared

ball magazines with defined storage positions. A similar situation comes with the join partner, the object where the ball has to be assembled to. Without an expensive camera system, the objects have to be well aligned and fixed in a defined position.

To improve these preparations, we developed a batch process to produce size adapted parallel micro grippers (see Fig. 1b and 1c) and active micro assembling devices like centrifugal feeders and clamping units (see Fig. 2 below).

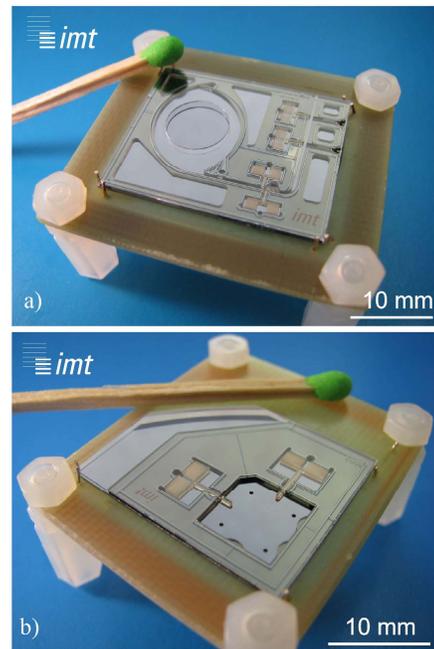


Figure 2: a) Micro-mechanical centrifugal feeder with separation unit b) micro-mechanical clamping unit.

Since the idea of developing additional tools for the micro assembling process arose during fabrication of the pneumatic micro grippers [2], the functional components of the auxiliary micro tools are similar in design to these already existing pneumatic systems.

All moving parts of the new devices are based on the pneumatic piston actuator concept, which has already been proved successfully in the grippers. Additional air nozzles are used to accelerate and transport the glass balls in the system.

## 2 FUNCTIONALITY AND BASIC DESIGN

Basically both mentioned devices are made of a perforated silicon base plate (containing pneumatic air in-

and outlets), a lithographically structured SU-8 layer (including all movable and fixed functional structures) and a patterned glass cover (filling holes).

The most important functional structure, the all over used pneumatic actuator, is made of a flexible and both-sides covered bellow structure ( $3600 \times 1400 \times 340 \mu\text{m}^3$ ) that deflects its piston ( $3000 \times 340 \mu\text{m}^2$ ) when air pressure is applied (see Fig. 3). The actuation movement is achieved by sealing gaps on top and bottom of the piston and the bellow structure. The later on described fabrication process produces gap dimensions of  $2 \mu\text{m}$  (sacrificial layer) on the bottom and  $3 - 6 \mu\text{m}$  on the top (adhesive bonding process). These small essential gaps lead to an inevitable but acceptable leakage air flow, which is guided away from the plunger and drained off through small outlet holes.

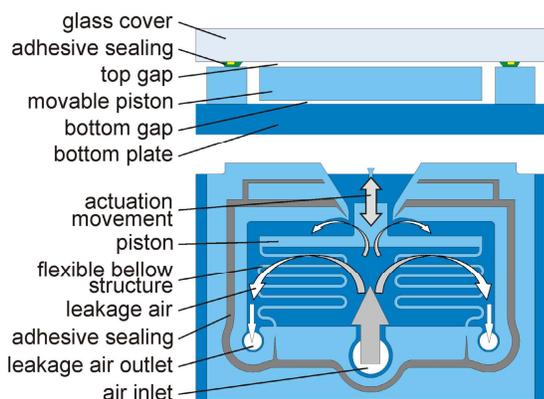


Figure 3: Schematic figure of the pneumatic actuator.

The pictured single piston actuator is driven by positive and negative pressure between 1 bar and -0.8 bar. Negative pressure pulls the piston backwards and positive pressure pushes it forwards. Thereby the actuation force and deflection can easily be steered by the operating pressure. For a simple piston, without a connected gearing, the actuation frequency can reach cycle times up to 250 Hz.

## 2.1 Centrifugal feeder

Fig. 4 shows the first device, a micro centrifugal feeder with integrated separation unit which is used to feed an assembling robot with  $200 \mu\text{m}$  to  $300 \mu\text{m}$  glass balls. The tiny bulk material is poured into the round storage chamber and circularly accelerated by air pressure from the chamber nozzle. A combination of centrifugal force and escaping air drives the glass balls into the outlet channel, where two pneumatic cylinders separate single globes and free them on demand. Additional channel nozzles push the balls through the channels and pneumatic actuators guide the balls to different outlets, where the robot can pick up the object at a defined position. Deceleration of the glass ball at its final pick-up-position is realized by an aspiration port in conjunction with a small bumper.

Using these basic elements, several different storage chamber variations, nozzle configurations, chamber air

drains, outlet channel shapes and aspiration ports were realized.

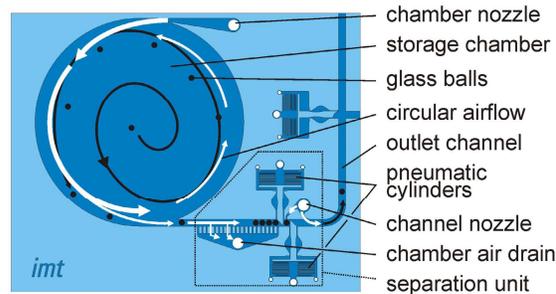


Figure 4: Schematic figure of the centrifugal feeder.

To avoid unexpected accumulations of the objects in the storage chamber, caused by disturbing turbulences or calm areas, all chamber variations (see Fig. 6) were optimized by using CFD simulations in the first place (see chapter 3).

## 2.2 Clamping unit

The clamping unit (Fig. 5) is designed to align small components (like mounting baseplates) automatically and fix them during the assembling process to avoid component slip. Pneumatic actuators are used to push and jiggle the handling object against multiple stoppers and finally clamp it in an aligned position. The fixation to the base is realized by vacuum holes underneath the object. In case of a matrix like arrangement of several clamping units, an active clamping magazine could be realized.

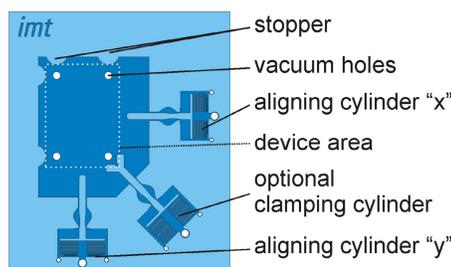


Figure 5: Schematic figure of the clamping unit.

The design variations for this device include three and four stopper arrangements and an optional clamping cylinder to hold the aligned component in position, even if all pneumatic supplies are disconnected.

## 3 SIMULATION

The numerical analysis of the centrifugal feeder was done by the finite element software CFD-RCTM (Version V2007) from the ESI-Group Inc. The following parameters were used for the simulations: air temperature  $20 \text{ }^\circ\text{C}$ , specific density  $1,204 \text{ kg/m}^3$ , dynamic viscosity  $1,846 \cdot 10^{-5} \text{ Pas}$ , unstructured mesh.

Another important parameter for the simulation is the entry velocity of the compressed air. Since this value depends on the used air supply, the switching valves and the used tube dimensions (all causing drop in pressure), this value was empirically determined with the later used experimental set-up. An air flow sensor and a hollow needle with length and cross-section similar to the contemplated outlet channel were connected to the valve-tube setup and the output velocity was measured for different preset pressures. In comparison with the micro gripper, where a maximum pressure of 1 bar is used, a maximum output velocity of 51 m/s was measured.

Several different entry velocities between 4 m/s and 51 m/s showed similar results on each chamber design. The chamber shape variations however showed greater differences in velocity distribution. Fig. 6 pictures four optimized designs with a nozzle entry velocity of 51 m/s. To reach a circular airflow with little turbulence in all chamber shapes, the elliptical (Fig. 6c) and the half circle chamber (Fig. 6d) had to be upgraded by an additional chamber nozzle. The dark (blue) regions show areas with low velocity magnitudes, building the center of the circular airflow. These areas are susceptible to result in “dead zones” for the objects and have to be as small as possible.

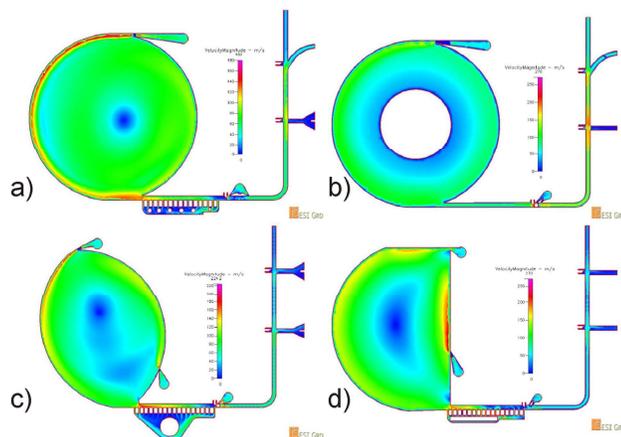


Figure 6: Airspeed distribution for different chamber geometries (entry velocity:  $v = 51$  m/s).

Further simulation focal points were the pressure distribution in the separation unit to guarantee a quick ball discharge of the piston-trap and the velocity distribution in the branching points of the outlet channel for secure air guidance of the objects.

## 4 FABRICATION

The fabrication process for the micro tools is presented in Fig. 7. First a 2  $\mu\text{m}$  chromium-copper sacrificial layer is sputtered onto a 360  $\mu\text{m}$  silicon wafer and patterned lithographically (step 1). Then a chromium etch stop layer, followed by a copper sealing layer is sputtered onto the bottom of the substrate. The subsequent spun on and

lithographically structured photoresist serves as a mask for the following ICP dry-etching process, which creates the air in- and outlets in the silicon bottom plate of the device (step 2). The metal layers are not affected. Now the resist is stripped and 340  $\mu\text{m}$  Epon SU-8 is spun onto the wafer and patterned by UV-lithography (step 3 and 4). The resulting SU-8 structures form all moving and mounting parts of the auxiliary tools. The movable structures are released by removing the sacrificial layers. This also removes the copper sealing layer, freeing the pneumatic bottom ports.

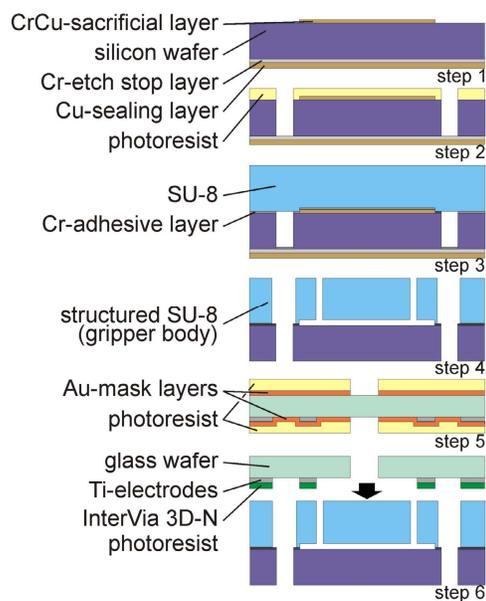


Figure 7: Process steps for the fabrication of active auxiliary tools.

The glass-cover is processed separately. First a titanium layer is sputtered and lithographically structured on a 200  $\mu\text{m}$  glass wafer. The structures function as conducting paths for the adhesive deposition later on. To pattern the filling holes in the glass top cover, a two-sided gold-photoresist mask is structured and the openings are etched in hydrofluoric acid (step 5). After removing the mask layers, interconnected conducting paths remain and serve as target areas for an electrodepositable photoresist, working as thermoplastic adhesive. Now both wafers are aligned and bonded in a heated vacuum-holder, which uses the outside air pressure to compress both wafers with a uniform force onto each other (step 6). Finally, all structures are separated with a dicing saw and glued to aluminum holders or a PCB-board (Fig. 2) with attached tube connectors underneath.

As the adhesive sealing defines the height of the gap between the glass cover and the bellow structure, the amount of adhesive has to be repeatable and on exactly defined positions on the wafer. The applied electrodepositable “adhesive” depositing method, uses the thermoplastic photoresist “Intervia 3D-N” as adhesive, and affords an easy way to achieve repeatable amounts of

adhesive on predetermined areas. Details to the adhesive deposition and the bonding process are explained in [2].

## 5 CHARACTERIZATION

To characterize the fabricated systems, an experimental setup containing a pneumatic control system with 16 fast switching valves, 4 proportional valves, vacuum generator and PC-interface, LabView software, a cold light source, and a high speed camera (FASTCAM 1024 PCI - Photron company) with attached PC-interface is prepared.

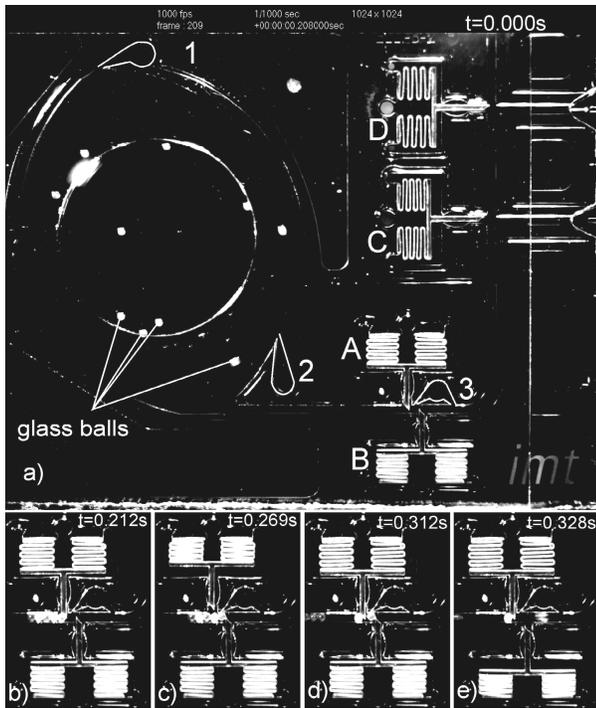


Figure 8: High speed camera pictures of the elliptical system a) and magnifications of the separation unit for varying times b-e).

After pouring 3 to 25 ruby glass balls (diameter  $300\ \mu\text{m}$ ) into the storage chamber, the opening is covered with a small glass plate (Fig. 8a). A typical testing sequence blows air with around 200 mbar (17 m/s) through both chamber nozzles 1+2 and accelerates the balls up to 8.5 m/s. Milliseconds later, some glass balls string in front of the separation unit (Fig. 8b). After 300 ms, piston A pulls the tappet back and the balls are pushed into the separation unit (Fig. 8c). After 30 ms, the piston moves forwards and separates a single ball (Fig. 8d). 20 ms later, piston B pulls backwards and frees the trapped ball. The outlet channel nozzle 3 accelerates the ball (Fig. 8e) to the deflection pistons C or D, which guides it to the correct outlet. After 20 ms, piston B returns and the next ball can be separated.

Repeatable tests with both round and elliptical systems prove that it is possible to release at least 6 balls in less than

840 ms on demand, if more than 5 additional balls are left in the system to guarantee a continuous ball supply. After the stringing sequence had occurred, releasing a single ball after another takes less than 90 ms per ball.

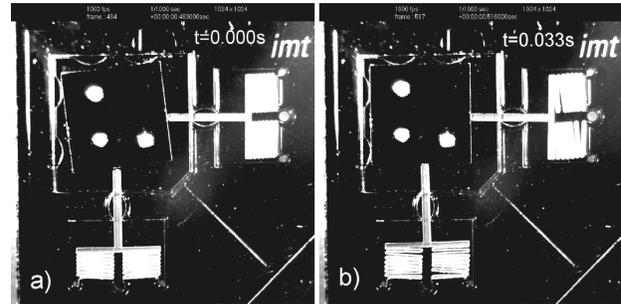


Figure 9: High speed camera pictures showing the clamping unit at the beginning and the end of the aligning process.

The experimental testing of the clamping unit occurred by placing a silicon chip with distorted orientation in the device area, followed by a sequence of simultaneous or alternating piston strokes. After jiggling the object against the stopper, vacuum holes in the bottom of the unit fix the chip at its position.

Multiple tests showed that simultaneous piston strokes can align and fix the object with the four stopper arrangement from the first strokes on (less than 80 ms). The alternating method needed more strokes (120 ms). Unlike to the four stopper method, the three bumpers sometimes caused device jamming.

## 6 CONCLUSIONS

This paper presents a size adapted design for a micro technological centrifugal feeder combined with a clamping unit for small desktop factories. Further on, it shows exemplary simulation results, the fabrication process and first characterization results. Both auxiliary micro tools were successfully tested and proved the practical realization of the laboratory prototype. The centrifugal feeder was able to repeatable release six  $300\ \mu\text{m}$  glass balls in less than 840 ms. The clamping device aligned silicon chips in 80 ms.

## REFERENCES

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