

# IMPACT FORCES REDUCTION FOR HIGH-SPEED MICRO-ASSEMBLY

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**Abstract** During the placement of components in micro-assembly, high impact forces occur. The current approach is to reduce these impact forces by coupling the gripper to the drive unit of the placement device with 5 DOF, wherein the gripper that contacts the component has a relatively low mass. To prevent the gripper from bouncing back at the end of the placement collision a force must be exerted between gripper and drive unit, which can significantly increase the impact forces. A solution has been found to realise an adequate force build-up between gripper and drive unit such that a rebound of the gripper is prevented without significantly increasing the impact forces. This solution can be implemented relatively easily by placing a spring between gripper and drive unit combined with a force limiter.

**Keywords** assembly, collision, force reduction, gripper, impact, micro system, rebound

## 1 Introduction

In micro-assembly, placement devices are used for assembling components or placing components on a substrate, e.g. a printed circuit board. During the placement motion it is generally not known exactly when the final position of the components will be reached due to tolerances of the component heights. Therefore components collide with a certain speed, leading to unwanted impact phenomena such as high contact forces and placement inaccuracies.

For the placement devices it is desired to have a high number of pick & place actions per minute, around 600 placements per minute averaged is state of the art. Second, low impact forces are crucial to avoid damage of the parts. This value is strongly depending on the component; state of the art is in the range of 0,10 to 8,00 [N]. Thirdly, high placement accuracies are needed (3-sigma better than 3microns). However, increasing the placement speed tends to increase the contact forces exerted by the gripper on the component or on the substrate. The current approach is to reduce these impact forces by moveably coupling the gripper to the drive unit of the placement device, wherein the gripper that contacts the component has a relatively low mass [1]. In such a setup the drive unit must exert a force on the gripper

to prevent the gripper from bouncing back at the end of the placement collision. A rebound is undesired as it causes a second impact, which increases the risk of:

- a) Damaging the component and/or substrate
- b) Increasing pollution of component and its environment
- c) Introducing vibrations in the placement device that cause significant inaccuracies in the placement of the component.

The impact forces can be reduced by lowering the impact speed, minimising the gripper mass or optimising the force between gripper and drive unit. In this article a method will be presented to reduce the impact forces by optimising the necessary force exerted on the gripper for preventing rebound of the gripper.

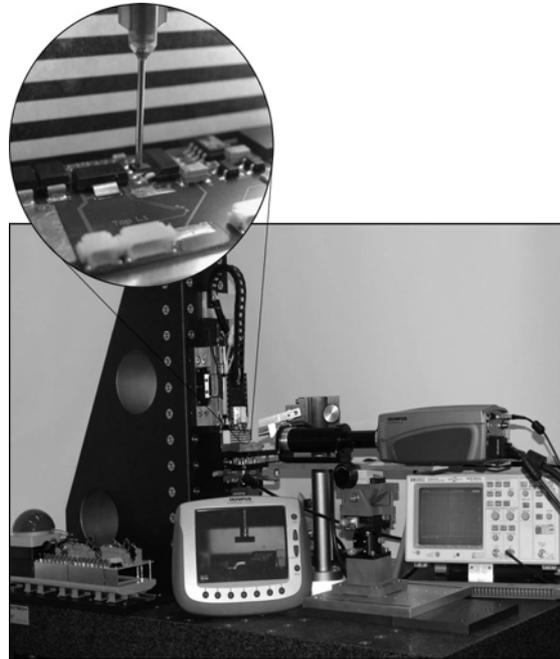
## **2 Problem analysis**

The primary goal of a Pick and Place robotic system is to efficiently mount components on the target surface, usually a Printed Circuit Board (PCB). This means there are time constraints, as well as accuracy constraints that have to be met. The problem is that these requirements are contradictory, a time optimised system lacks competitive accuracies and vice versa [2].

During the collision, when the gripper holding the component, is hitting the target surface, energy is transferred in elastic and plastic deformation. The elastic energy is not absorbed in the system, but only stored temporarily, like energy stored in a spring. Instead of storing the kinetic energy of component and gripper in the flexible structure, some parts of the system suffer from permanent deformation. These parts, usually the material around the contact points between target structure and components, act as a damped spring system. The energy that is not transformed to elastic deformation will be absorbed by the components. This could lead to damage of the component. The failure mechanism, caused by the absorbed energy is not subject of investigation in this publication but will be addressed in a separate paper.

The elastically stored energy (stored spring energy) will be partially converted back to kinetic energy of the gripper at the end of the collision. The gripper will therefore tend to bounce up again. In a test setup, this could be registered with a high-speed camera (Figure 1). Multiple bounces, as much as ten times would occur before the component showed no movement.

The obvious solution for preventing the gripper and the component from bouncing is to continuously exert a force of a larger magnitude between gripper and target surface. In state of the art equipment, this is done with a pretensioned spring with flattened spring-characteristic. Now we come to the real difficulty; the maximum reaction force of the elastically deformed component will determine the load of this pretensioned spring. This load however will increase the impact force thus leading



**Fig. 1.** Experimental setup for impact analysis including a z-stage for controlling the placement motion, a high-speed camera for observing the impact phenomena and a scope for measurements. The z-stage is build-up from a linear motor which can reach accelerations of up to 60g. The high-speed camera with additional set of microscope lenses is able of filming with a frame rate of 10.000 fps with a resolution of less then 2 micrometer per pixel.

on its term to a higher reaction force again. The result would initially lead minimal reduction of rebound.

The collision process is typically non-linear [3-6], so increase in collision force will lead to a higher amount of plastic deformation and elastic amount of deformation remains of the same order. If the extra downwards directed load is strong enough, elastic deformation, that causes the rebound has become relatively low so the contact force will be maintained during all stages of the collision and there will be no rebounding. However, because this extra force is significantly higher than the necessarily placement force, there will be stronger impact, more plastic deformation and higher risk of damaging the components and/or the substrate.

### 3 Research and development

The hypothesis was that an adequate force build-up on the gripper for preventing rebound could be realised by placing a small spring **in the gripper, as near to the component as was mechanically possible**. The spring was combined with a force limiter, to limit placement forces when board height suffers from tolerances (when component touches the board before or after the expected moment) [7-10].

By tuning the spring constant, the force on the gripper can be built-up in a controlled way during the placement collision such that the impact forces are not increased significantly. The force limiter, e.g. a pretensioned spring with low stiffness, prevents the force on the gripper of becoming too big when the drive unit continues moving relative to the gripper during the placement collision.

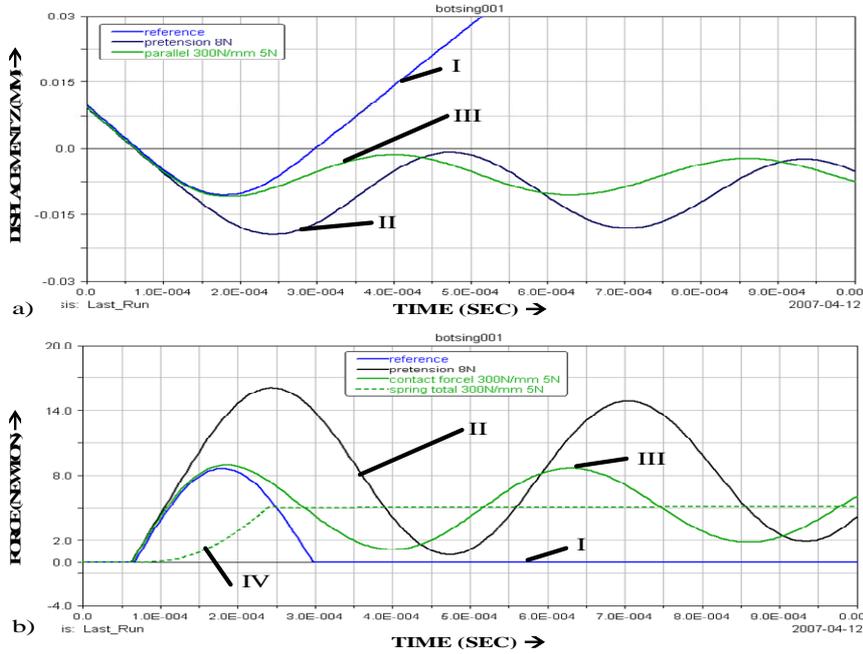
For optimising the force to be exerted on the gripper to prevent rebound, the collision of the gripper with component on a substrate has been modeled as a single degree of freedom damped mass-spring system. The equivalent parameters of the model have been determined by conducting a series of experiments (Figure 1) with a gripper, with 1 DOF remaining, mounted to the drive unit without any extra force added between gripper and drive unit. During the experiments the impact speed, rebound speed and contact duration of the first collision has been measured. The experiments showed that within the measurement range of the collision speed (50-350) mm/s, the contact duration was not significantly influenced by the collision speed. The collision duration was also found out to be almost linearly proportional to the mass of the gripper. Therefore a spring with constant spring stiffness is used to represent the deformations of gripper, component and substrate leading to the following equations of the lumped parameter model [11, 12]:

$$m_{collision} \cdot \ddot{z} + c_{collision} \cdot \dot{z} + k_{collision} \cdot z = F_{drive\_unit} \quad (1)$$

$$m_{collision} = m_{gripper} + m_{component} \quad (2)$$

$$k_{collision} = m_{collision} \cdot \left( \frac{2\pi}{t_{contact}} \right)^2 \quad (3)$$

$$c_{collision} = \frac{2 \cdot \ln \left| \frac{v_{rebound}}{v_{impact}} \right| \cdot m_{collision}}{t_{contact}} \quad (4)$$



**Fig. 2.** Simulation result of collision between gripper and base structure , mass gripper 4.4 g, equivalent collision stiffness 821 N/mm; *a)* displacement curve of gripper, zero height is top surface of base structure, negative length represents deformation of material around contact points, *b)* contact force curve, I/ free moving gripper guided by drive unit, II/ gripper guided by drive unit and pretensioned spring between gripper and drive unit with pretensioned force just big enough (8N) to prevent rebound of gripper, III/ gripper guided by drive unit and spring combined with force limiter between gripper and drive unit, stiffness spring 300 N/mm, pretension force of force limiter 5N, IV/ resultant force between gripper and drive unit for spring combined with force limiter.

in which  $m$  is mass,  $k$  is spring stiffness,  $c$  is damping,  $z$  is distance between gripper/component and substrate (negative value represents a deformation of the material around the contact points) and  $t_{contact}$  is time between first moment of contact between gripper/component and substrate and the moment at which the contact is broken due to a rebound of the gripper and component. In the model an extra spring between gripper and drive unit can be added of which the stiffness can be tuned such that the force on the gripper builds up just fast enough to prevent rebound and subsequently the force build-up can be limited as much as possible by adding a force limiter (see Figure 2a).

The simulations showed that in the new solution (with spring) the impact forces could be reduced to almost half of the impact forces that occur with the general solution of exerting a constant force to prevent rebound (see Figure 2b).

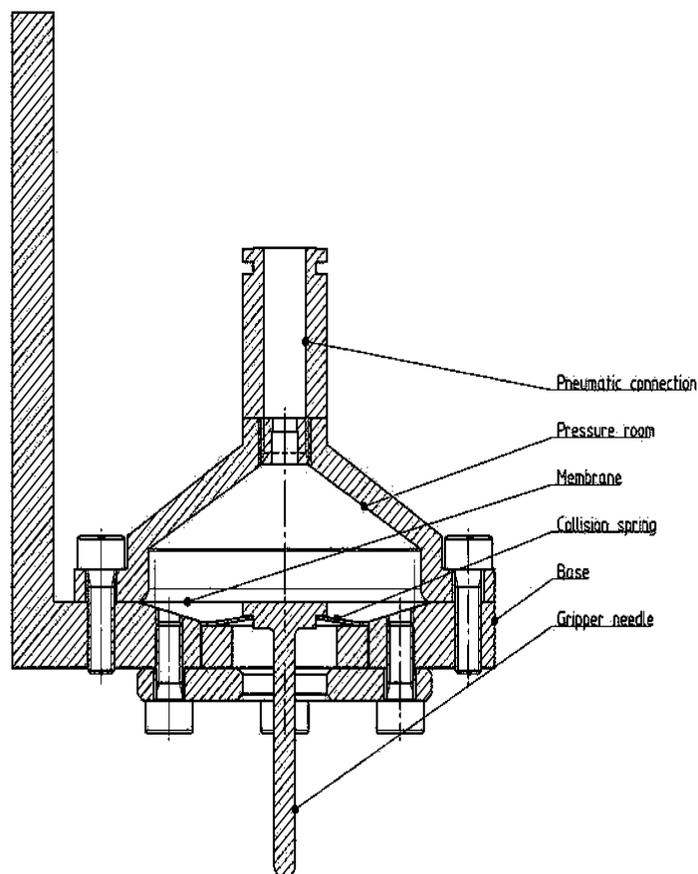
## 4 Design

The spring and force limiter must be combined such that at the start of the placement impact the force build-up is controlled by the spring making the force depended on the distance between gripper and drive unit. After the force has reached a predetermined value the force limiter must make the force independent of the distance between gripper and drive unit. The force limiter is needed to prevent the force on the gripper of becoming too high when the drive unit continuous moving towards the substrate while the gripper/component is already in contact with the substrate. The spring and force limiter can either be placed in series or parallel. The parallel configuration is preferred because then less mass is involved in the collision since both spring and force limiter are connected to the drive unit. In this configuration both spring and force limiter exert a force on the gripper but in opposite direction. At the start of the placement collision, both elements exert the same force leading to no resultant force on the gripper. During the collision the spring will be depressed making the spring force smaller then the force of the force limiter, resulting in a higher force on top of the gripper. After the spring is completely depressed until it is zero length, it will loose contact with the gripper making the force on the gripper depend only on the force limiter. An air spring has been chosen as force limiter because it has a relative low stiffness and the force can be controlled easily. For the spring a cupped spring washer has been used to make it possible to change the stiffness easily. For the guidance between gripper and drive unit a membrane has been used giving a low weight symmetrical design. The design of the gripper prototype is shown in Figure 3. In a further design the gripper has been equipped with a vacuum needle and the spring and vacuum supply have been integrated in the holder structure.

## 5 Results

A prototype of the developed gripper has been build and tested (see Figure 3b). In the prototype the force build-up could be tuned by changing a cupped spring washer and by regulating the pressure on the membrane. When a cupped spring washer with the highest available stiffness is used a situation is created similar to the general solution of using a constant force between gripper and drive unit to prevent rebound. The test results showed that when the cupped spring washer with the highest available stiffness was replaced by one with the stiffness found with the simulation, the pretension force on the membrane could be reduced with 35%. With a cupped spring washer, with a stiffness that was too low, rebound of the gripper could not be prevented at all. These test results were in close accordance with the simulation results (see Figure 2) showing that by simply adding a spring with the right stiffness, the impact forces can be reduced with 50% compared to the general solution of having a constant force between gripper and drive unit.

With the further developed gripper also a low mass (less than 1 g) of the parts involved in the collision (e.g. component, gripper needle, guidance, vacuum supply)



**Fig. 3.** Prototype of developed gripper for micro assembly: a) drawing gripper prototype, b) realized gripper prototype. Note the “collision spring”, which takes care of preventing the rebound. The mass of the gripper needle can be reduced more; this will lead to further increase of performance.

has been realised. Additionally the placement accuracy has been improved by adding a tilting member in the gripper, which prevents the gripper of becoming over-constrained during the placement collision.

Patents are pending for the solution of “reduced impact for micro-gripper” and for the designed “statically determined gripper”.

## 5 Conclusion

The impact forces during component placement can be reduced significantly by optimizing the force exerted on the gripper for preventing rebound of the gripper. An adequate force build-up can be realised by placing a spring between gripper and drive unit combined with a force limiter. In this way a real time mechanical solution can be realised in a relative simple way for preventing rebound of the gripper while keeping the impact forces minimal.

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