EXTENDING ADAT2 EQUIPMENT LIFETIME

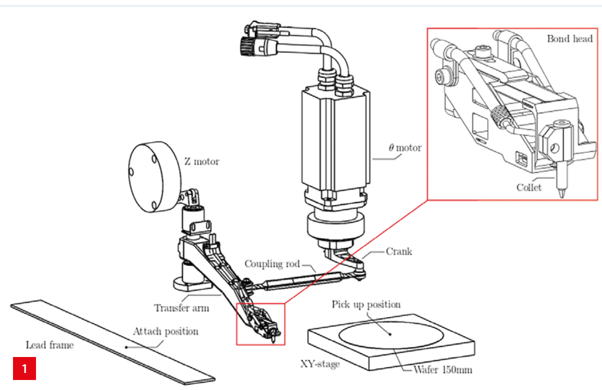
ITEC's ADAT2 (Automatic Die ATtach) systems, developed in the 1990s, are still operational in various production sites. An upgrade enabling them to handle 200-mm wafers would extend their economic lifetime even further. To this end, the design of an intermediate rotary stage was investigated.

HARM SCHEPENS

Introduction

ITEC (Industrial Technology & Equipment Center) is a leading supplier of back-end semiconductor equipment, located in Nijmegen (NL). ITEC is well known for its reliable ADAT (Automatic Die ATtach) platforms, comprising the ADAT2, developed in the 1990s, the newer ADAT3, conceived in the early 2000s, and the ADAT3 XF, introduced in 2015. The ADAT3 and ADAT3 XF systems can handle larger wafers and offer higher productivity. However, the ADAT2 platform is still operational in various production sites, where the machines produce 24,000 products per hour (24k), 24 hours a day, 365 days per year.

These sites would benefit greatly if, instead of replacing the machines with state-of-the-art systems, the economic lifetime of the ADAT2 machines could be extended with a cost-effective upgrade kit. This upgrade should enable the machines to handle the larger 200-mm wafers at a lower 18k productivity (maintaining 24k would be a bonus). The ADAT2 high-speed pick & place machine (Figure 1) uses a lightweight carbon-fibre transfer arm in combination with a collet fitted onto a bond head in order to transfer dies from a diced wafer (pick-up position) to a lead frame (attach position). A low vacuum is applied through the collet, so the die remains fixed during motion. During placement, the collet undergoes peak accelerations of up to 150 g.



1 *Schematic overview of the ADAT2 high-speed pick & place mechanism.*

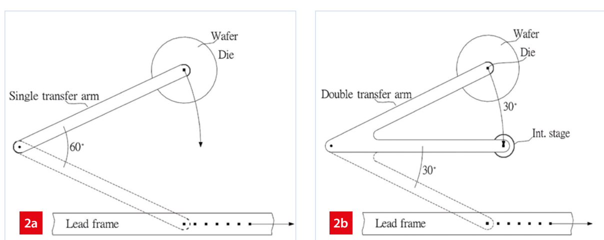
Increasing throughput

During its lifetime, the ADAT2 system has been upgraded multiple times, generally to enhance throughput. To this end, the drive train stiffness was increased and dynamic behaviour improved. The latest upgrade kit replaced aluminium and steel parts with carbon-fibre retrofits, which resulted in excellent properties regarding weight, stiffness and dynamic behaviour. These properties were optimised to such an extent that there was arguably not much room for further improvement in this area. Also, the ADAT2 platform was not suitable for wafer sizes above 150 mm, which was what prompted ITEC to investigate the possibility of an upgrade for wafer size.

The throughput time in ADAT2 operation consists of several phases that can be optimised:

- picking time;
- motion time;
- settling time;
- placement time.

In the approach followed here, the focus is to shorten the motion time by reducing the transfer distance of the dies. Currently, the dies are moved over a distance of approximately 240 mm by a transfer arm travelling a stroke of 60°. This distance can be reduced with a concept that uses a new transfer arm in combination with an intermediate stage. The new transfer arm can be fitted with two bond heads, so that two dies can be transferred simultaneously. The 'double-transfer arm' transfers the dies over a distance of

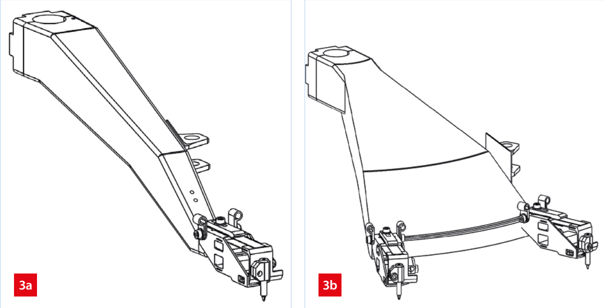


Schematic overview of the existing and the new solution.
(a) Single-transfer arm.
(a) Double-transfer arm.

AUTHOR'S NOTE

Harm Schepens is a mechanical engineer at Nobleo Technology in Eindhoven (NL). He obtained his master's degree in Mechanical Engineering at Eindhoven University of Technology. This article is based on his thesis work.

harm.schepens@nobleo.nl
www.nobleo-technology.nl

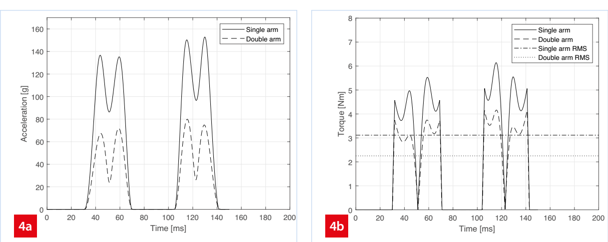


SolidWorks motion simulation models of the two solutions.
(a) Single-transfer arm.
(b) Double-transfer arm.

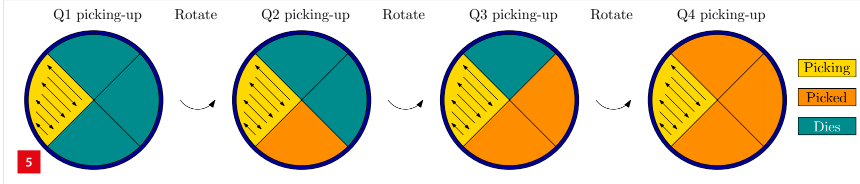
approximately 120 mm with a stroke of 30°. For clarification, in Figure 2 the new procedure is schematically represented and compared with the existing 'single-transfer' solution.

During the first cycle, the double-transfer arm places a die on an intermediate stage, then during the second cycle two dies are simultaneously moved from the wafer to the intermediate stage, and from the intermediate stage to the lead frame. With the double-transfer arm, the transfer of a single die from the wafer to the lead frame takes more time. However, the system throughput is not defined by the transfer time of a single die; it is determined by the motion time of a single stroke (30° vs. 60°). At first glance, the double-transfer arm seems counter-intuitive because it is larger/heavier and will not be able to operate with the same accelerations as the single-transfer arm. However, the double-transfer arm travels only half the stroke of the single-transfer arm and therefore requires lower velocities and accelerations.

A first-order-of-magnitude study was performed to estimate the impact of the double-transfer arm. Two simulation models, representing the single- and double-transfer arms, respectively, were created to compare driving torques and accelerations at the bond head. The two simulation models and the resulting motion profiles in acceleration and torque are shown in Figures 3 and 4.
The graphs show the decrease of the required torque at equivalent throughput. The models have not been optimised yet, but clearly the graphs show that there is an upward potential in terms of throughput for this concept. The down-side of using a double-transfer arm is that it requires an intermediate stage to place a die and pick up the same die.



Results of the simulation models of Figure 3 (for the 24k setpoint).
(a) Acceleration profiles.
(b) Torque profiles.



Altered picking-up process in which the wafer is rotated in Rz.

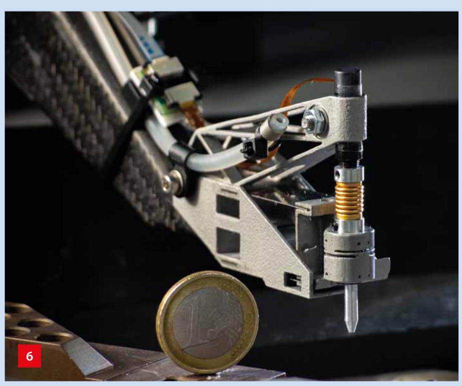
This means that the transfer of a single die from the wafer to the lead frame needs more interactions and involves an increased risk of die chipping. The picking up of the dies and their landing on the lead frame is a controlled process. However, the interactions with the intermediate stage are tricky: dies may chip when the impact forces are too large. To prevent the dies from chipping, a new concept for an intermediate (rotary) stage was required, which is addressed below.

Increasing wafer size compatibility

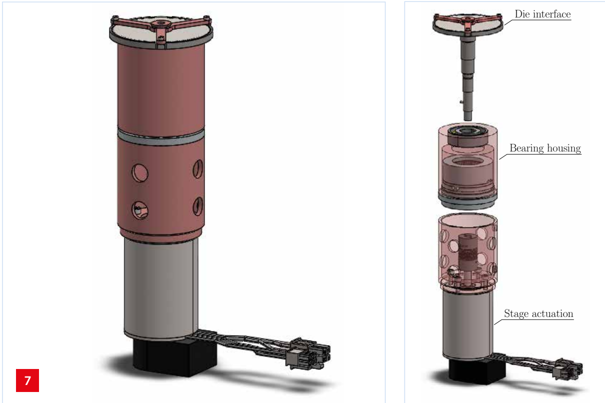
The current ADAT2 platform is capable of handling a 150-mm wafer. In order to handle wafers of 200 mm, the stroke of the XY-table needs to be increased. This is not possible, however, due to volume conflicts. Therefore, a different solution is provided: the XY-table can be upgraded to an XY-Rz-table in combination with an altered picking-up process, which is represented schematically in Figure 5. In the new process, dies from a quarter of the wafer are picked up first and then the wafer is rotated 90°, after which dies from a second quarter can be picked up. This process is repeated until the wafer is empty. The altered process makes it possible to cover the entire wafer, but when the wafer has been rotated (and thus the dies), the dies have to be de-rotated before being placed on the lead frame. This correction has to been done between picking up the die from the wafer and placing it on the lead frame. The intermediate (rotary) stage is an ideal location for performing this task.

Rotating collet

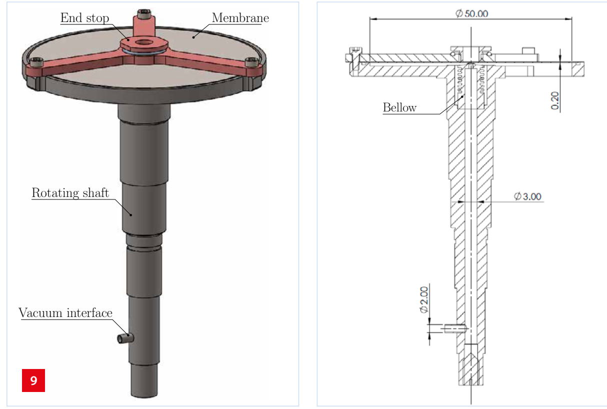
A rotating collet as an alternative solution for die de-rotation was also investigated. Figure 6 shows the concept design, 3D-printed in aluminium. A bellow coupling is used to couple the collet and the motor shaft's rotation, while releasing the other degrees of freedom. The motor mass does therefore not contribute to impact forces on the die. It does, however, pose a risk for dynamic performance, because mass is added at the tip of the transfer arm. A rotating collet enables 200-mm wafer capabilities for the ADAT2, but increasing throughput may be a challenge.



Rotating collet (a coin was included in the image for size reference).



The intermediate stage with an exploded view on the right.



Die interface with a section view on the right.

Intermediate (rotary) stage

The intermediate stage consists of three sub-assemblies: the stage actuation, the bearing housing and the die interface. The stage actuation consists of an actuator with a motor coupling that drives the die interface, which is subsequently mounted backlash-free in the bearing housing. The 3D model with an exploded view highlighting all the sub-assemblies is shown in Figure 7.

Stage actuation
The stage is actuated with a commercial off-the-shelf maxon motor. This will not be discussed further.

Bearing housing
The bearing housing holds two angular contact ball bearings to constrain the rotating shaft radially and axially. The concertina holder can be used to mount the bearings without any backlash and elimination of all play. This design is directly inspired by Wim van der Hoek's design principles as depicted in his "*Des Duivels Prentenboek*". The 3D model and a section view of the bearing housing are shown in Figure 8.

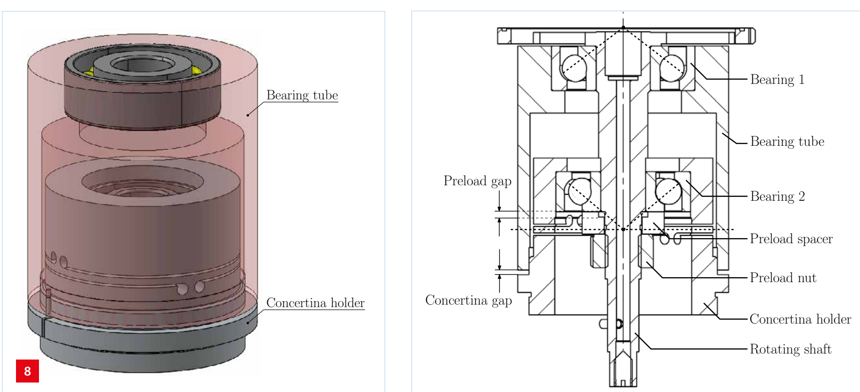
Die interface
When using the rotating stage as an intermediate step in the process, each individual die makes more impacts; this increases the chance of die chipping. The die interface is designed to reduce the impact forces on the dies when they are placed, and hold the dies in position during the orientation correction (de-rotation). The sub-assembly of the die interface and a section view are depicted in Figure 9.

The interface consists of a membrane that is connected to a rotating shaft via a bellow, an end-stop and a vacuum interface. The vacuum interface is used to apply a small vacuum to the dies through the rotating shaft and a small hole in the membrane (visible in Figure 10). The vacuum ensures that the die remains in contact with the membrane during the orientation correction.

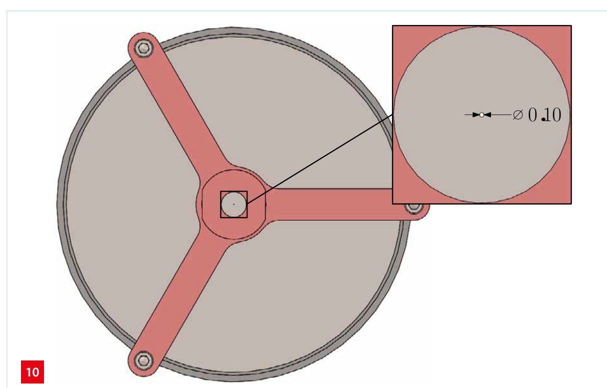
The first problem that was tackled in this design was the reduction of impact forces in order to prevent dies from chipping. The impact force can be calculated according to the following equation:

$$F_{\text{impact}} = v_0 \sqrt{mc}$$

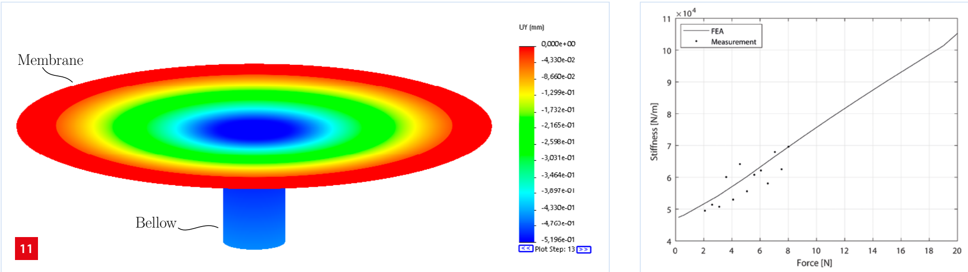
The equation shows that the impact force can be reduced by lowering the impact velocity of the dies, or the mass and the stiffness of the landing surface. It is not desirable to lower the impact velocity in the process, for reasons of throughput, so only two parameters can be altered. The simplest design that can satisfy the requirement for both parameters is a membrane, since it has relatively low stiffness and mass.



Bearing housing with a section view on the right.

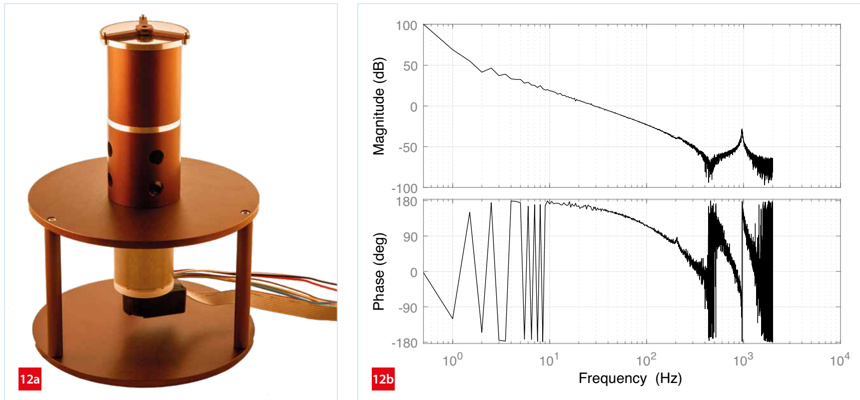


Vacuum hole in membrane.



FEA model with the corresponding stiffness plot on the right.

Since the stiffness is of paramount importance for this membrane, it has been optimised using finite-element analysis (FEA). The FEA model and its resulting stiffness graph are shown in Figure 11; note that the stiffness increases with deflection, which is typical for a membrane. From the FEA plot it can be concluded that the initial stiffness of the stage is approximately 48 N/mm and increases to approximately 105 N/mm when 20 N is applied. The actual measurements on a functional model (fumo, see below) over a range of 2 to 8 N yielded matching values for the stiffness and its increase over the force range. This indicates that the FEA yields an accurate representation of the design model and that reduction of impact forces on the dies can be achieved.



Functional model (fumo).
(a) Design.
(b) Measured Bode plot.

Functional model

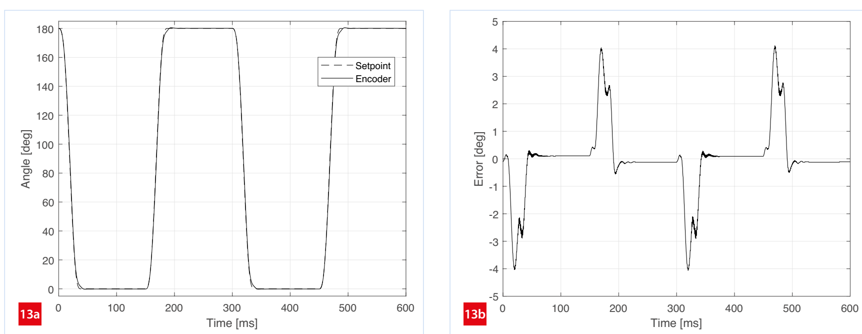
The 3D model was converted into a fumo in order to verify whether the stage can correct the rotation within the available time frame, impact forces can be reduced, and dies can be gripped. The resulting fumo and its corresponding Bode plot are given in Figure 12.

Measurements have been performed on the fumo to verify the design assumptions. A controller was designed and a minimal servo bandwidth was calculated to guarantee that the rotation can be executed within the motion time of the transfer arm. The setpoint with encoder signal and the resulting tracking error are given in Figure 13. Note that the stage is within the specified orientation correction (the maximum required value of 180° was set here) after 39 ms, while the specified time budget for this action was 45-62 ms.

Rendering of the upgraded ADAT2 system with the intermediate rotary stage.

Conclusion and outlook

This study has shown that the ADAT2 lifetime can be extended in terms of 200-mm wafer size compatibility. The next step would be to implement the (prototype-quality) fumo in an existing ADAT2 platform (which would require a few adaptations for mounting) and verify if die chipping can be prevented when dies are placed on the intermediate stage. Figure 14 shows how the rotary stage would fit in the existing machine with a double-transfer arm.



Setpoint.
(a) Encoder signal.
(b) Resulting tracking error.