Design of the Matchmaker

The driving force behind the ever-increasing density of components on printed circuit boards (PCBs) is the miniaturisation of handheld equipment for component placement. PCB technology went from Thru Hole to Surface Mount and currently there is a growing presence of components that have the contacts on their blind side, as is the case with Ball Grid Arrays (BGAs). This article describes the design and use of a semi-transparent mirror in component placement for superimposing the image of the contact side of a component with the image of the corresponding tracks on the PCB.

• ***Hans van den Brink and Ruud Bons*** •

In the early 1990s, the first vision systems for component placement based on a semi-transparent mirror appeared on the market. In March 1992, an article was published in the IBM Technical Disclosure Bulletin [1] that described an ingenious cube beam splitter with an additional mirror that allowed for simultaneous looking up and down. Pick & place equipment based on this principle was sold by, among others, Zevac. At about the same time, Finetech introduced the Fineplacer, a joint development with the Fraunhofer Institute, which employs a cube beam splitter. Because the view is at right angles, the placement arm rotates over 90 degrees and the prism is in a fixed position.

Matchmaker

In 1994, a patent was granted on a novel beam splitter, a semi-transparent mirror sandwiched between two identical optical substrates. When looking under an angle, the apparent displacement in transmission is equal to the one in reflection. Placement is done by rotation, the angle of rotation typically being in the order of 2 x 20 degrees, a compromise between ease of handling and optical aberration. At the time, a semi-transparent mirror deposited upon a membrane was considered the state of the art, but it was not suitable for application in a taxing atmosphere.

Authors

Hans van den Brink (M.Sc. Physics, Delft University of Technology, the Netherlands) worked with E.G.&G. in the USA and with Philips. After retirement he became self-employed in the area of laser systems and consultancy. In the 1990s he conceived the idea of the Matchmaker. Ruud Bons is a mechanical engineer at Technobis Mechatronics in Uitgeest, the Netherlands.

vdbrinkconsultancy@planet.nl
www.technobis.nl

The system was baptised 'Matchmaker'. The three systems are shown schematically in Figure 1.

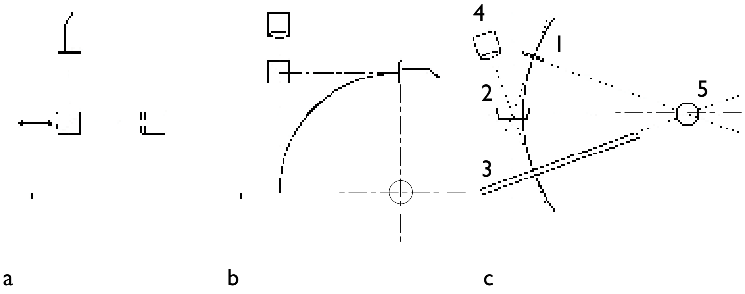

Figure 1. Schematics of component placement vision systems based on a semi-transparent mirror.
(a) IBM.
(b) Finetech.
(c) Matchmaker: 1. component, 2. semi-transparent mirror, 3. PCB, 4. objective, 5. rotation axis.

An initial series of four Matchmakers was produced for testing, demonstration and evaluation. The accuracy was adequate for the then current BGAs. For reasons that go beyond this article, no follow-up was conducted until 2004. In the meantime, miniaturisation progressed ever further and lead was being banned from solder. Lead-containing solder in the liquid phase has a high surface tension, as a result of which a poorly placed BGA will align itself during soldering. With the new lead-free solder, accurate positioning prior to placement becomes necessary – preferably at an affordable price.

Rotatory versus linear placement

The overwhelming majority of pick & place systems employ a vertical movement of the component. The exceptions are Finetech and Matchmaker. Placing along a straight line can be looked upon as using an infinitely long arm. In a rotating system, the component lands along the tangent of the circle and as such has a limited depth of 'mechanical focus' compared to the straight movement. To give an indication: with a 150 mm placement arm, a premature landing of 1.2 mm in the vertical direction will cause a horizontal placement offset of 5 µm.

Superimposing images

A perfect match in component placement requires that object and image are at exact opposite positions of the mirror. To assess the required accuracy, the tolerance budget has to be calculated (see below). When a component is picked up at its top side and it is the image of the bottom side that should be 'at the exact opposite position', then there is a complication: components vary in thickness, up to several millimetres. The Matchmaker solves this problem, as shown in the cycle of the process steps in Figure 2. Here the mirror holder is multifunctional, acting also as a loading platform for the component.

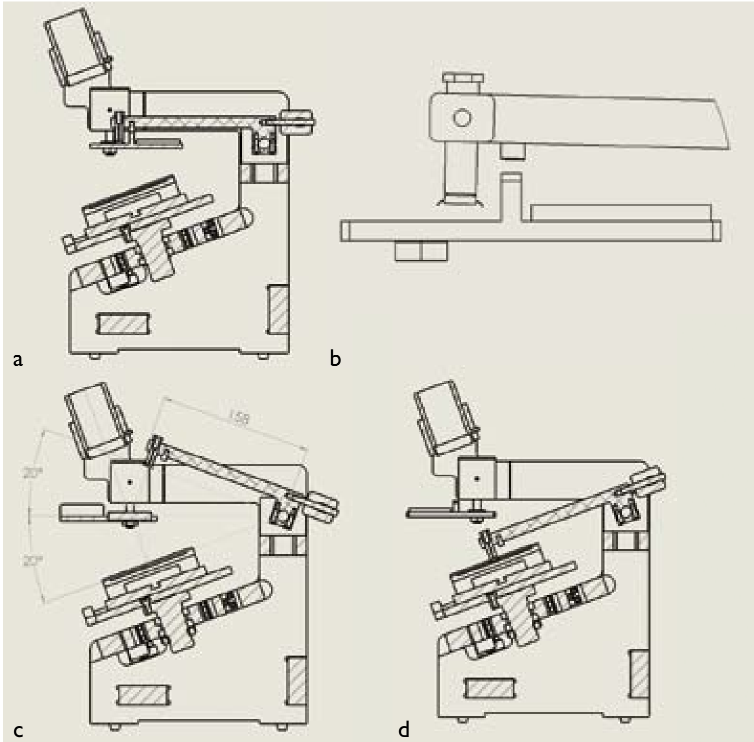

Figure 2. Operation of the Matchmaker.
(a) After rotation of the mirror holder, the component is picked up.
(b) The downward rotation of the pick-up arm is stopped by a limiter; the vacuum pick-up then goes down until it meets the top of the component.
(c) The position of the vacuum pick-up is fixed relative to the head of the pick-up arm and the arm is lifted to its upper position. The semi-transparent mirror in the optical path, the image and the objective are aligned.
(d) The mirror holder rotates to clear the way for the pick-up arm with the component on its way to the PCB. This is also the start of loading the next component.

Tolerance budget

To facilitate a design that meets the required accuracy, the allowable tolerances in position and/or orientation of the various parts or subassemblies with regard to one another were considered in a systematic fashion. At the outset of the design phase, the target for placement accuracy was set at +/-5 μm. Here, placement accuracy is defined as follows: if the operator achieves a perfect match between the image and the object, after placement the match should be within +/-5 μm. It is understood that with the eye as detector the actual match depends on the operator's care and skill.
In the following analysis of a selection of potential 'errors' it is assumed that all other conditions are met perfectly. As this is not realistic, the requirements for orientation and position should be a factor 10 tighter. An approach to get at least partially around this problem is offered below (section on Design philosophy). This is the result of progressive insight.

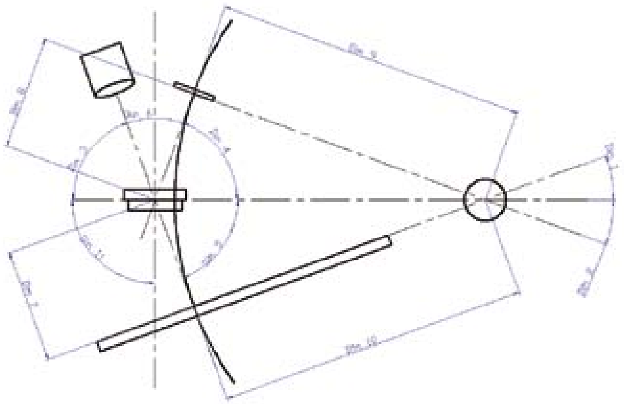

Figure 3. Definition of the dimensions and their nominal values as used in the tolerance budget exercise.

Dimension	Nominal value
1	20°
2	20°
3	70°
4	70°
5	70°
6	40°
7	54.60 mm
8	54.60 mm
9	150 mm
10	150 mm
11	90°

Error conditions

This section discusses several relevant 'error conditions' emerging from the tolerance budget calculations. As stated before, the acceptable mismatch of a BGA component on the PCB is 0.005 mm.

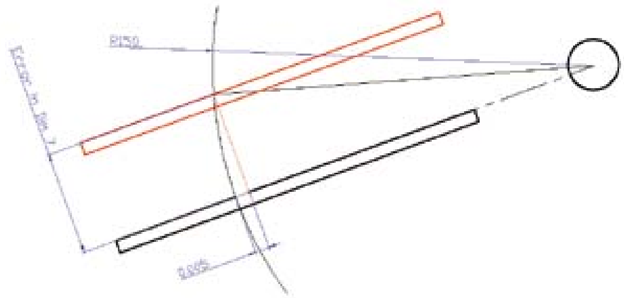

Figure 4.

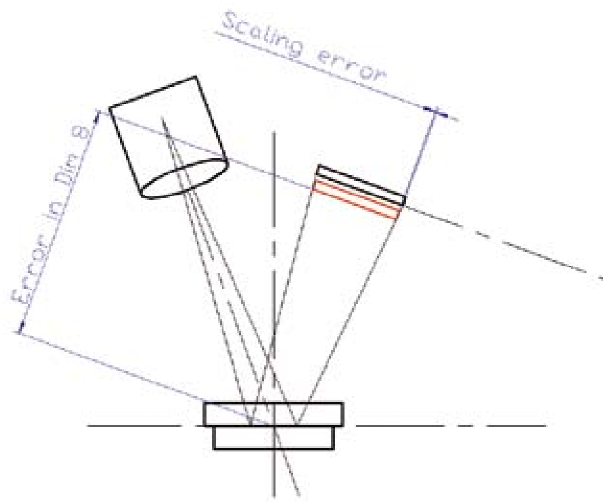

Figure 5.

- The PCB is not in line with the rotation axis (see Figures 4 and 5)
  An error of 1.2 mm in Dim 7 causes Dim 10 to go from 150 mm to 149.995 mm, a mismatch of 5 μm. This 1.2 mm error constitutes the 'mechanical depth of focus'. For a number of applications this is sufficient. However, Figure 5 shows what will happen in the field of view if the image of the contact side of the component floats 1.2 mm above the PCB.

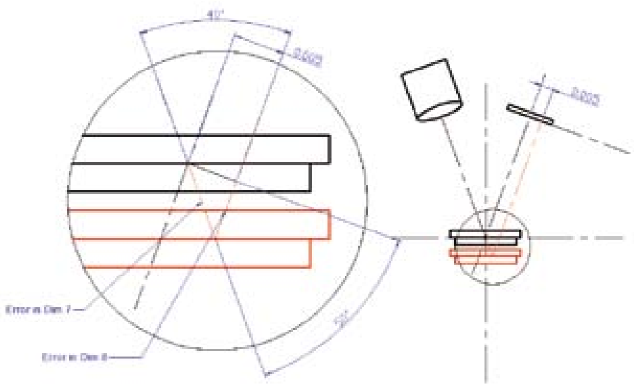

Figure 6.

- The mirror is not in line with the rotation axis (see Figure 6)
  If the mirror for instance has been lowered by 0.008 mm (Dim 7 decreasing, Dim 8 increasing), Dim 9 decreases from 150 mm to 149.995 mm. It can be concluded that the position of the mirror relative to the centre line through the rotation axis is the most critical aspect.

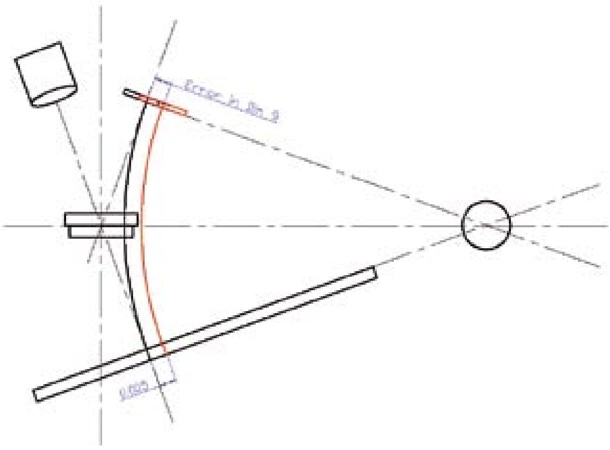

Figure 7.

- The placement arm is too short (see Figure 7)
  Dim 9 and Dim 10 are each other's mirror image; there is no effect on placement accuracy. This in itself is interesting since it means that effects of, for instance, temperature change on the length of the arm do not affect accuracy.

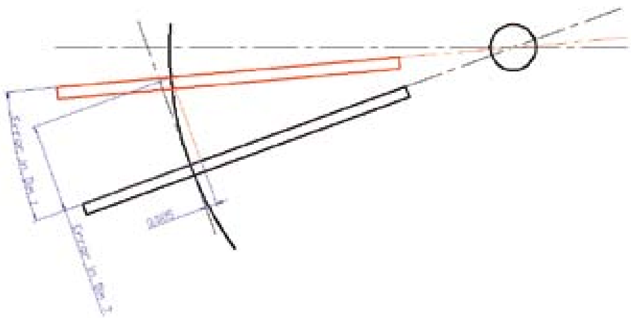

Figure 8.

- The mirror does not bisect the BGA and PCB planes (see Figure 8)
  This situation is similar to the one in Figure 4. Incorporated into the design is the feature that the upper position of the placement arm has an adjustable limiter, enabling the mirror to bisect the two planes.

Conclusions

Some of the most relevant results of the calculations regarding the 5 μm placement accuracy target have been presented. It has become evident that the position of the mirror relative to the rotation axis is the most critical aspect. In the analysis of an individual potential error it was assumed that 'everything else' was perfect. As this does not represent reality, the effect is that the tolerances have to be tighter than presented. The effect of temperature changes has not been taken into account, as it is assumed that the axis is positioned in some kind of thermal centre. The effect of optical drift is shown in Figure 5. If the PCB is flat and the component has been picked up from the plane of the mirror, the drift should be minimal.
To meet the required accuracy, there is just one realistic option and that is to assemble the Matchmaker in such a way that parts and subassemblies are put into position by means of calibration.

Design philosophy

The placement arm rotation axis (axis 1) should be straight. Its position is determined by the frame and it should be mounted free of play. Axis 1 is dominant. On the adjusting platform, the reference plane of the PCB holder should point at the centre line of axis 1, say with an accuracy of 0.1 mm. The mirror holder assembly rotates free of play around axis 2 and is perpendicular to this axis. Two

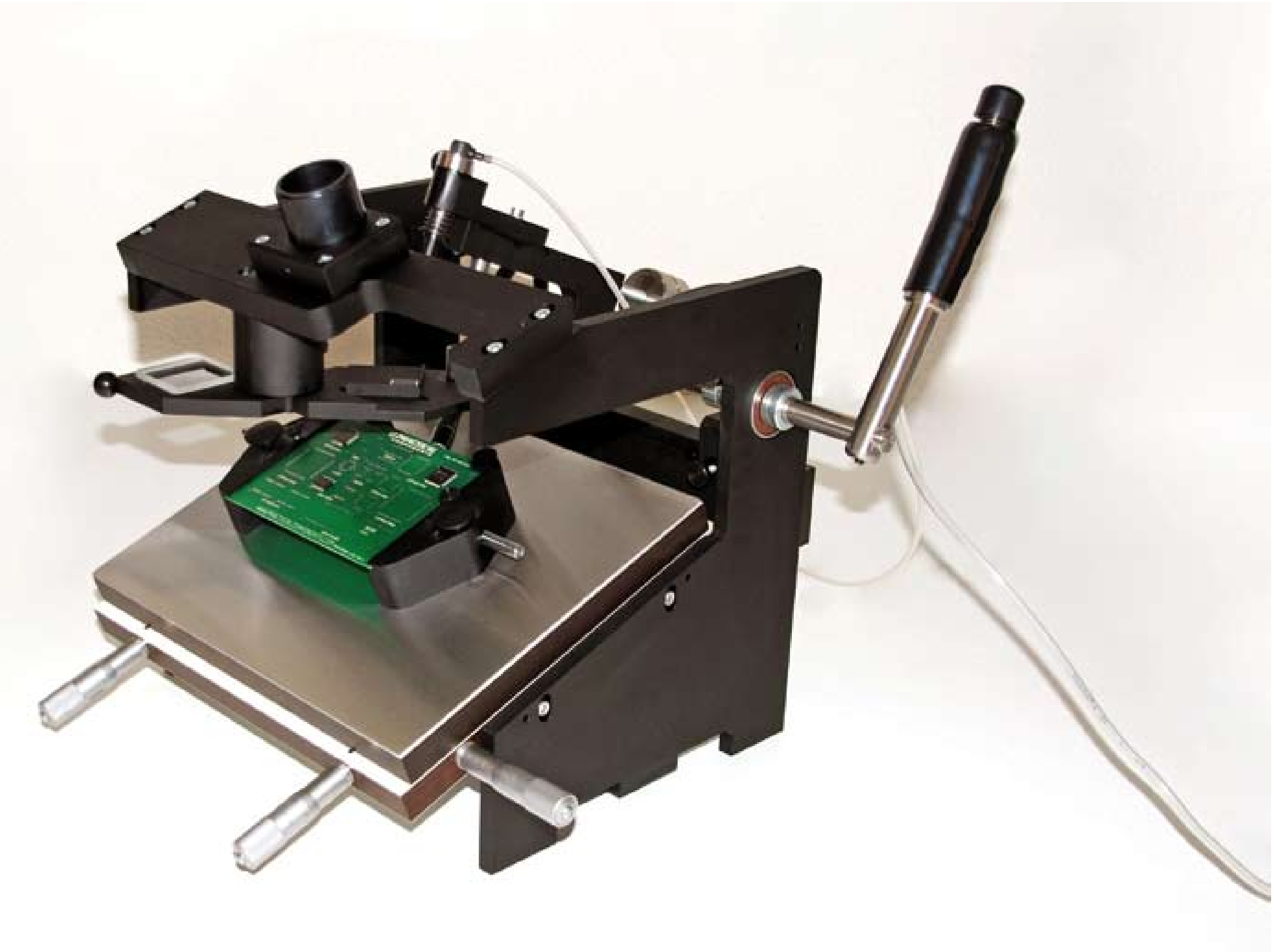

Figure 9. Current version of the Matchmaker. (Photo: Technoprint)

conditions must be met: axis 2 should be perpendicular to axis 1 and the plane of the mirror should point at the centre line of axis 1.
In order to avoid unrealistic demands on the accuracy of the production parts, it was decided to make the mirror housing adjustable in height and direction relative to axis 1. This may be at the expense of Dim 7, but this can be compensated by making Dim 8 equal to Dim 7 by means of the adjustable limiter that controls the upper position of the placement arm.

Epilogue

As mentioned in the introduction, there are three different approaches to 'splitting the beam'. The tolerance budget drawn up for the beam splitter of the Matchmaker is basically applicable to all three systems. The pick-up procedure of the Matchmaker with its automatic compensation for the thickness of the component is, so far, unique. Figure 9 shows the current version of the Matchmaker, built by Technoprint in Ermelo, the Netherlands.

Reference

[1] *Precision superposition component placement tool for endpoint sensing*, IBM Technical Disclosure Bulletin, 1992, Vol. 34, No. 10B, pp. 4-6.