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RESEARCH ARTICLE

Investigating the self-alignment of chip components during reflow soldering

Olivér Krammer / *Zsolt* Illyefalvi-Vitéz

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Abstract

Since the application of lead-free soldering has become obligatory in the electronic industry by the 1^{st} of July 2006, the in-depth analysis of the soldering process is more important than ever. The small chip components of the present days demand very accurate component placement machines to prevent common reflow failures such as skewing or tombstoning. The ability of components to be self-aligned during soldering works against these failures, therefore it matters to what extent the solder promotes this effect. Dynamic behaviour of SMT (Surface Mount Technology) chip components during lead-free reflow soldering will be demonstrated in the paper. A force model has been introduced with the five main forces which determine the movement of the chip component during reflow soldering, namely: the force originating from the surface tension, the forces originating from hydrostatic and capillary pressure, the force of gravity, and the force of dynamic friction.

The self-alignment of 0603 size chip components has been investigated by real experiments. SM chip components are misplaced intentionally by semi-automatic pick&place machine, and before and after reflow soldering the exact location of components was measured. The results have shown that the self-alignment of components does occur even in the case of 400-500 μm lateral misplacements. The explanation of the equations of the applied theory and the results of the experiments are presented in the paper in details.

Keywords

reflow soldering · self-alignment · chip components · surface mount technology

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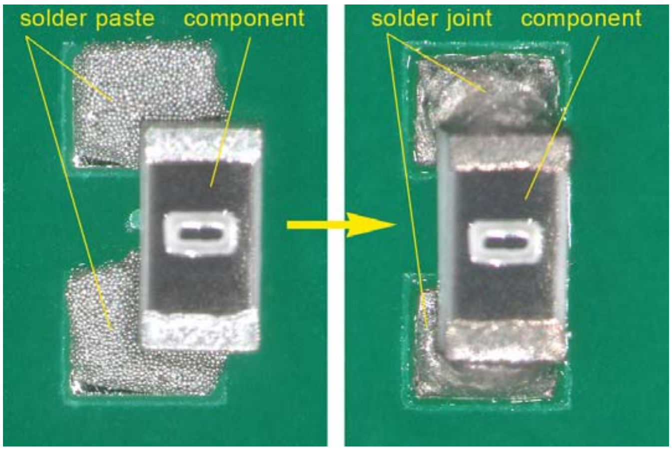
Olivér Krammer
Zsolt Illyefalvi-Vitéz
Department of Electronics Technology, BME, H-1111 Budapest Goldmann Gy. t. 3., building V2, Hungary

1 Introduction

Nowadays the most widespread assembling technology of electronic circuit modules applies reflow soldering. This technology basically consists of three steps. At first the solder paste (which contains flux and the solder alloy) is deposited onto the pads of the printed wiring board (PCB). The second step is the component placement, where surface mounted (SM) components are placed into the deposited solder paste by automated placement machines. Then the third step is remelting of the solder alloy in a reflow oven, where the solder joints are formed. The small chip components of these days (size 0201 to 01005 – 600x300 μm to 400x200 μm) demand very accurate component placement machines in order to prevent common reflow failures such as skewing or tombstoning. Fortunately the components have ability to be self-aligned during reflow soldering (Fig. 1) due to the forces originating from the molten (liquid) solder. The component self-alignment works against the above mentioned reflow failures; therefore it matters to what extent the solder promotes this effect.



a. b.

Fig. 1. The self-alignment of SM chip component, a. misplaced component in the solder paste before soldering, b. soldered component

1.1 Theoretical background of the component self-alignment

Among the forces, which have effect on the chip components during reflow soldering, the force originating from surface tension is the most robust, mostly it forces the components to move. The balance of the surface tension in a three-phase system, where liquid-solid-gaseous phases coexist, can be described by the Young's equation (1) as illustrated by Fig. 2.

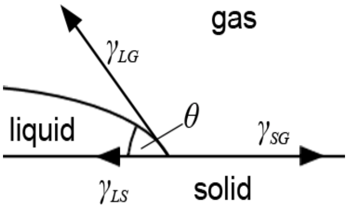


Fig. 2. Surface tension of a three-phase system

$$\gamma_{SG} = \gamma_{LS} + \gamma_{LG} \cdot \cos\theta \tag{1}$$

γ_{LG} – surface tension of the liquid-gas boundary
γ_{SG} – surface tension of the solid-gas boundary
γ_{LS} – surface tension of the liquid-solid boundary
θ – contact angle

1.1.1 Former force models – the Wassink-Verguld model

At the early stage of reflow soldering technology simple force models have been created in order to study the motion of chip components during reflow soldering. The first force model has been described by Wassink and Verguld [9]. It is a simple two dimensional force model, which purpose is to determine the moment acting on the chip component during soldering in order to prevent the tombstoning of component (Fig. 3). The model takes the following forces into consideration:

- Force due to gravity (rotates the component counter-clockwise)
- Force due to the surface tension of the solder under the component: $F\gamma_1 = \gamma_1 \cdot d$ (rotates the component counter-clockwise), where d is the width of the component
- Force due to surface tension of the solder on the face of the component:
  $F\gamma_2 = \gamma_2 \cdot d$ (rotates the component clockwise)

The model assumes that there is no solder on the left face of the component and it considers the solder fillet as a straight line instead of a curve. In addition the model, due to its simple manner, does not take into consideration the hydrostatic pressure of the liquid solder. Therefore complex motions of SM chip components during reflow soldering cannot be treated by the Wassink-Verguld model because of its above mentioned deficiencies.

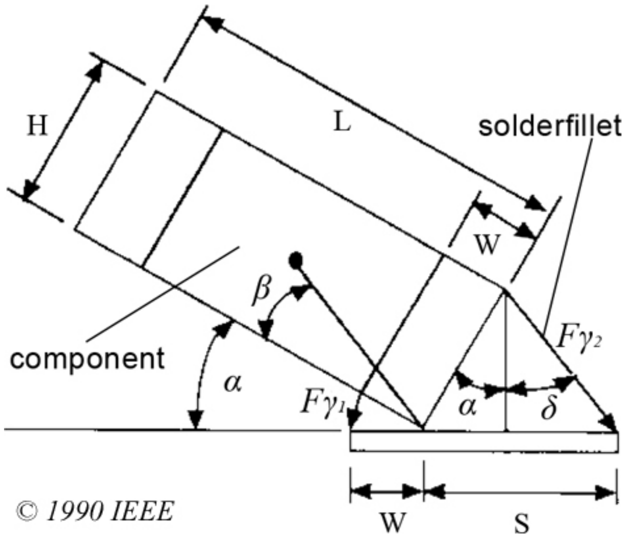


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Fig. 3. The Wassink-Verguld model [9]

1.1.2 The Ellis-Masada model

A more complex model has been described by John R. Ellis and Glenn Y. Masada [3], which takes into consideration the hydrostatic and capillary pressure of the molten solder and considers the solder fillet as a curve (Fig. 4), however it is a two dimensional model as well as the Wassink-Verguld model. The model comprises further simplifications; it assumes that the component is brick-shaped (i.e. rectangle in two-dimensional model) and its mass centre is in the geometrical centre of the body. In addition the model supposes that the P point is always in contact with the soldering surface (pad) and the component rotates around that P point.

The moment balance is taken about the pivoting end of the chip component (P point) as illustrated by Fig. 4. A counter-clockwise moment is considered positive. The net moment acting on the component can be described by the following equations based on the model. The model considers the moments as uniform in z direction, and the expressions are related to a small dz length of the component width (d) in direction z, the moments divided by unit length $\left[\frac{N}{m}\right]$ are denoted with upper index*.

$\sum M_p^* = M_{t1}^* + M_{p1}^* + M_{t2}^* + M_{p2}^* + M_w^*$ is the net moment, where the terms are the followings.

- M_{t1}^* is the moment originating from the surface tension of the solder under the component:

$$M_{t1}^* = \gamma\, W \sin\theta_1 \tag{2}$$

which can be derived by the following way:

$$\frac{d}{dz}d(z) \cdot \gamma \cdot W \sin\theta_1 = \frac{d \cdot \gamma \cdot W \sin\theta_1}{d} = \gamma\, W \sin\theta_1 \tag{3}$$

- M_{p1}^* is the moment originating from the hydrostatic pressure acting on the bottom metallization of the component:

$$M_{p1}^* = -\frac{F_{p1}}{d} w_c \tag{4}$$

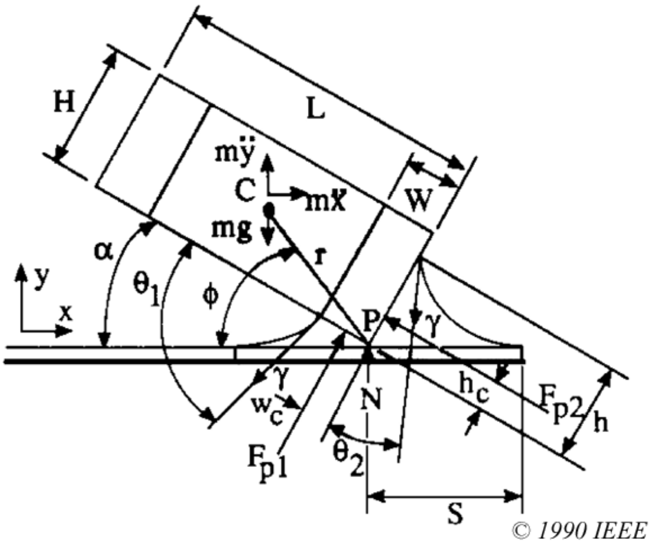

Fig. 4. The Ellis-Masada model [3]

- M^*_{t2} is the moment originating from the surface tension of the solder on the face of the component:

$$M^*_{t2} = -\gamma\, h \sin\theta_2 \tag{5}$$

- M^*_{p2} is the moment originating from the hydrostatic pressure acting on the face metallization of the component:

$$M^*_{p2} = -\frac{F_{p2}}{d} h_c. \tag{6}$$

- M^*_w is the moment due to the gravitational force:

$$M^*_w = mg\left[\frac{L}{2}\cos\alpha - \frac{H}{2}\sin\alpha\right]\frac{1}{d}, \tag{7}$$

where:

- $mg\cos\alpha$ and $mg\sin\alpha$ are the force components of the $m\vec{g}$ vector perpendicular and parallel to the longer side of the component respectively, and $mg\sin\alpha$ has a minus sign because the moment due to it rotates the component clockwise,
- $\frac{L}{2}$ and $\frac{H}{2}$ are the distances of force components from P point.

The forces due to hydrostatic pressure (F_{p1} and F_{p2}) can be calculated by the principle of pressure continuity (section 1.2.1) by the aid of expression (11):

$$F_{p1} = (\Delta P_0 - \rho g \frac{W}{2}\sin\alpha)\cdot A = (\Delta P_0 - \rho g\frac{W}{2}\sin\alpha)\cdot W\cdot d,$$
$$F_{p2} = (\Delta P_0 - \rho g\frac{h}{2}\cos\alpha)\cdot h\cdot d, \tag{8}$$

where ΔP_0 is $P_{\text{solder}} - P_{\text{atmosphere}}$ at the end of the solder pad.

The distances (h_c and w_c) of the forces due to hydrostatic pressure (F_{p1}, F_{p2}) from the P pivoting point are computed using a model of a flat plate submerged into a liquid [3]:

$$w_c = \frac{w}{2} - \frac{\rho g\sin\alpha\cdot w^3 d}{12 F_{p1}}$$
$$h_c = \frac{h}{2} - \frac{\rho g\cos\alpha\cdot h^3 d}{12 F_{p2}} \tag{9}$$

Based on the above described expressions the force balances on the chip in x and y directions are the following:

$$\sum F_x = \gamma\ [\sin(\theta_2 - \alpha) - \cos(\theta_1 - \alpha)] +$$
$$F_1\sin\alpha - F_2\cos\alpha - b\dot{x}_c = m\ddot{x}_c, \tag{10}$$

$$\sum F_y = -mg - \gamma\ [\cos(\theta_2 - \alpha) + \sin(\theta_1 - \alpha)] +$$
$$F_1\cos\alpha + F_2\sin\alpha + N = m\ddot{y}_c, \tag{11}$$

where b is the viscous friction coefficient between the solder and chip metallization [Newton-seconds] and N is the normal force acting on the chip component at the contact point (Newtons).

Although the model includes many specific details; the meniscus of the solder is not considered to be a straight line, the force due to hydrostatic pressure is taken into consideration and the chip component is allowed to be displaced along its pad length to illustrate the effect of component misplacements, it is still a two dimensional model and three dimensional motion of the components cannot be described. Newer models describe mainly the motion of IC packages such as BGAs or Flip-chips [4, 5, 11] and there is no complex 3D force model for SM chip components. However, the size reduction of SM chip components made concern about the component self-alignment during reflow soldering, therefore we decided to create a three dimensional model to determine the motion of SM chip components.

1.2 Theoretical background of determining the shape of the solder fillet

First of all the topic of predicting the dynamic behaviour of chip components during reflow soldering should be divided into two parts. The first issue is to determine the shape of the molten solder fillet, while the second issue is to calculate the forces, which are acting on the component, by the known fillet. There are two main theoretical approaches for determining the shape of the molten solder; calculating the equilibrium shape by minimizing the energy [6–8] of the system or applying the pressure continuity principle [3].

1.2.1 Predicting the solder fillet by applying the principle of pressure continuity

The principle of the pressure continuity is that in a static solder fillet, no pressure gradients exist horizontally and the pressure in the vertical direction changes proportionally to the distance from the liquid surface (i.e. proportionally to the height of liquid coloumn). Consequently, since the fillet profile decreases in height in the function of distance from the chip component, a continuously changing pressure difference must exist along the profile as illustrated by Fig. 5.

To find the pressure drop across the fillet, ΔP, Laplace's equation is used to relate the pressure drop and the fillet surface ge-

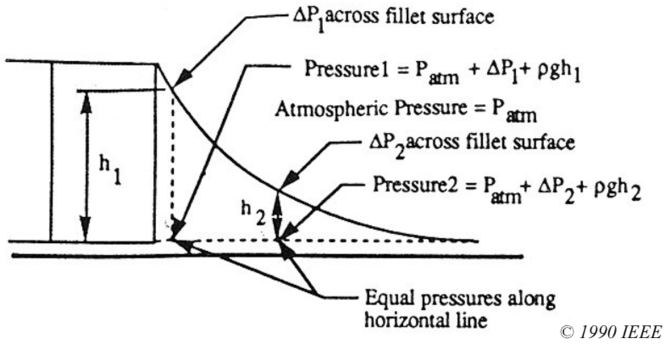

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Fig. 5. Pressures in the solder fillet [3]

ometry. In its most general form the equation is:

$$\Delta P = \gamma \cdot \left(\frac{1}{r_1} + \frac{1}{r_2} \right), \tag{12}$$

where r_1 and r_2 are the radii of curvature of the fillet measured normal to the surface of the component face metallization. For two-dimensional models equation (11) will be simpler, r_2 can be equal to infinity (no curvature), thus $1/r_2$ is zero. Therefore:

$$\Delta P = \gamma \cdot \frac{1}{r_1} \tag{13}$$

The definition of curvature for a two-dimensional curve $y = y(x)$ is:

$$\kappa = \frac{\frac{d^2y}{dx^2}}{\left[1 + \left(\frac{dy}{dx}\right)^2\right]^{3/2}} = \frac{1}{-r} \tag{14}$$

Using the bottom of the fillet as a datum, and ΔP_0 at the bottom of the fillet as the reference point for calculation of the pressure and applying the y function to describe the fillet profile, ΔP_0 can be written as:

$$\Delta P_0 = \Delta P + \rho g y, \quad \Delta P = \Delta P_0 - \rho g y \tag{15}$$

since an increase in height decreases the pressure across the solder fillet and the P_{atm}can be withdrawn, because it does not change in any direction in the case of small bodies like the solders or components.

Substituting (13) and (15) into (14) and solving for (d^2y/dx^2):

$$\frac{d^2y}{dx^2} = \frac{1}{\gamma} \left(\rho g y - \Delta P_0\right) \cdot \left[1 + \left(\frac{dy}{dx}\right)^2\right]^{3/2} \tag{16}$$

Eq. (16) is a second-order nonlinear differential equation whose solution defines the fillet profile. Once the correct profile is known, the points at which the surface tension forces and pressure forces act can be computed. In this approach two boundary conditions are needed (i.e. the solder wets until the end of the pad and the height of the solder fillet is equal to the height of the component) and ΔP_0 is an unknown, but for a three dimensional force model this principle cannot be used to determine the fillet profile.

1.2.2 Predicting the solder fillet profile by minimizing the energy of the system

The equilibrium shape of a liquid meniscus at a liquid-gas phase boundary of a system - in which solid, liquid, and gaseous phases coexist - is given by a balance of forces acting on the system. In the case when the boundary condition is that the solder wets until the end of the metallization and the contact angle depends on the volume of the solder, the energy of the system which should be minimized is given by Eq. (17) [5–7]:

$$E = E_S + E_G \tag{17}$$

E_S – energy due to surface tension = $\sum\limits_{i}^{LS,LG,SG} \int\limits_{A} \gamma_i dS$
E_G – energy due to gravity =$\int\limits_{V} \rho \cdot g \cdot z \cdot dxdydz$
γ_i – surface tension coefficient
ρ – solder density
g – gravitational constant
A – surface of the fillet
V – volume of the solder

When the boundary condition is that the end of the pad is not reached by the solder, thus the contact angle is equal to the wetting angle, as can be seen in Fig. 6, Eq. 18 forms as the following [10]:

$$E_S = \sum_{i}^{LS,LG,SG} \int\limits_{A_0} \gamma_i dS + \sum_{i}^{LS,LG,SG} \int\limits_{A_1} -\gamma_i \cdot \cos\theta_1 dS + \sum_{i}^{LS,LG,SG} \int\limits_{A_2} -\gamma_i \cdot \cos\theta_2 dS \tag{18}$$

A_0 – boundary area of the solder and the gas
A_1 – boundary area of the solder and the pad
A_2 – boundary area of the solder and the component metallization
θ_1– wetting angle on the contact line of solder and the pad
θ_2– wetting angle on the contact line of solder and the component

Actually Eq. (18) is separated form of Eq. (17), where the surface of the solder is separated into three parts. The contact line of the solder is moving on the soldering surfaces toward inside of the solder, decreasing the total energy of the system. Hence the second and the third term have to be subtracted from the first term in Eq. (18). Since only that component of force (force originating from the surface tension), which is parallel to the contact line movement, acting on the system, γ_i in second and third term has to be multiplied by $\cos\theta$.

By solving Eq. (17) with any of the boundary conditions the shape of the molten solder can be determined. Since the solder joints are quite small, the dominant term in Eq. (17) is the first one, i.e. the energy due to the surface tension. The forces which are acting on a component can be calculated by the known fillet profile.

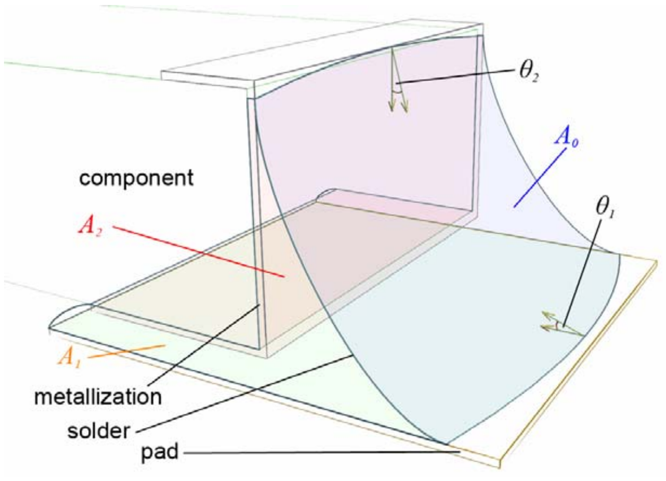

Fig. 6. Boundary surfaces of the molten solder

2 Experimental analysis concerning self-alignment of SM chip components

Mainly five forces are acting on a chip component during reflow soldering. The force originating from surface tension is acting on the boundary contact line of the three phases i.e. solder, gas, and component metallization. The forces originating from hydrostatic and from capillary pressure are acting on the area of the metallization of the component; while the force originating from dynamic friction depends on the mass of the liquid solder which should be actuated. The fifth force is the gravitational force.

2.1 Description of the three dimensional force model

In the case of component misplacements (due to the placement machine inaccuracy) the main force, which promotes the self-alignment, is originating from the surface tension of the liquid solder. In a three-phase system, where gaseous-solid-liquid phases coexist (Fig. 2); the balance between the surface tensions (γ_{LG}, γ_{SG}, γ_{LS}) can be described by the Young's equation (1). The force, which is originating from the surface tension, acts on the appointment place of the solder, gas, and component metallization. In general case the appointment place of a three-phase system is a space curve, which is called as contact line in soldering technologies. Therefore the net force originating from the surface tension can be obtained by integrating the terms due to surface tension along the contact line (18), which is determined by the previously calculated solder fillet:

$$\vec{F}_{st} = \sum_{i}^{LS,LG,SG} \int_{\upsilon} \gamma_i d\vec{l} \tag{19}$$

The forces, originating from hydrostatic- and capillary pressures of the molten solder, push the component out from the solder. These forces are acting on the vertical face- and bottom side metallization of the component as illustrated by Fig. 7 (F_h and F_c). The capillary pressure is the pressure difference between the two sides of a curved liquid surface. The pressure drop across the fillet (ΔP), can be determined by the Laplace's Eq. (11). The hydrostatic pressure inside a liquid can be described by Eq. (19) in general form:

$$P_h = \rho_l \cdot g \cdot h \tag{20}$$

ρ_l – density of the liquid
g – is the gravitational constant
h – the height of the liquid column

The principle of the pressure continuity is that in a static solder fillet, no pressure gradients exist horizontally and the pressure in the vertical direction varies proportionally to the distance from the liquid surface [3], thus it likes as though the h height of the liquid column is balanced by the ΔP capillary pressure. Therefore for example the capillary pressure at s line can be calculated by any point, which takes place above the s line ($n_i \in A_1$), as illustrated by Fig. 8. The s line is infinitesimally close to the bottom side metallization of the component.

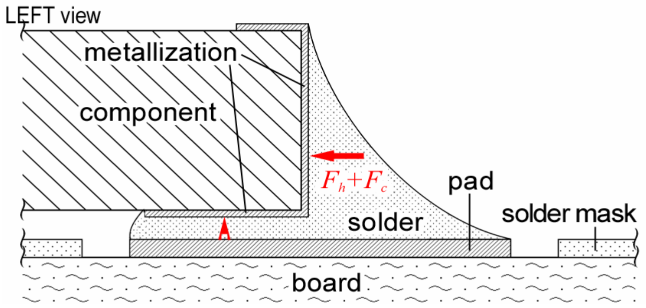

Fig. 7. Forces due to hydrostatic- and capillary pressures

The force originating from hydrostatic- and capillary pressures ($\underline{F}_p$) can be determined by integrating pressure values along the surface of the component metallization (20):

$$\vec{F}_p = \int_{A_{cs}} (\rho_s g \cdot h(\vec{r}))d\vec{S} + \int_{A_{cs}} \left(\gamma_{LG}\left(\frac{1}{r_1(b(\vec{r}))} + \frac{1}{r_2(b(\vec{r}))}\right)\right)d\vec{S} \tag{21}$$

A_{cs} – surface of component metallization
ρ_s – density of the molten solder
$h(\vec{r})$ – height of the liquid column, which is infinitesimally close to the point designated by the $\vec{r}$ vector on the A_{cs} surface
$b(\vec{r})$ – point on the top of the liquid column, where the capillary pressure should be calculated

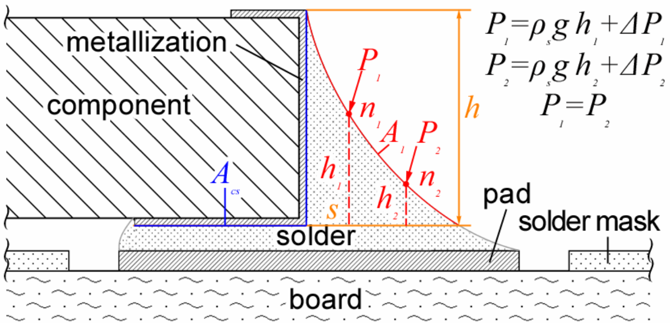

Fig. 8. Principle of pressure continuity

The dynamic friction between the liquid and the solid phases slows the movement of the liquid phase. Hence the dynamic friction of a liquid is actually the viscosity of that liquid. In our case the dynamic friction reduce the self-alignment of the component. The liquid (molten solder) can be imagined as a series of horizontal layers. The top layer in the molten solder is infinitesimally close to the bottom side metallization of the component, and its speed is equal to the speed of the component movement. The speed of bottom layer is 0, equal to the speed of the pad (Fig. 9). Anywhere inside the molten solder, the speed of an upper layer is higher than the speed of a lower layer; microscopically the molecules of the upper layer are colliding with the molecules of the lower layer and a part of the faster molecules kinetic energy transforms to heat energy.

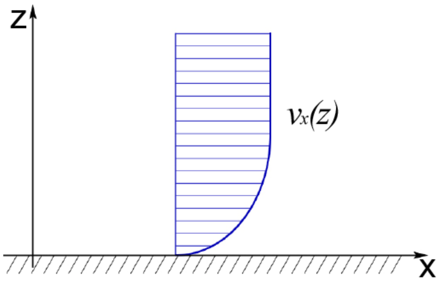

Fig. 9. Speed of a liquid in the function of distance from the fixed z plane

The force, originating from the dynamic friction between a solid and a liquid phase, can be described by the Newton equation (21) [1,2]:

$$F = \eta \cdot A \frac{dv}{dz} \tag{22}$$

In our case, when the component is moving in the molten solder, the solid phase is the metallization of the component; therefore the surface of the metallization should be taken into consideration. Thus the decelerating force (22) of the component can be written as the following:

$$\vec{F}_v = \int\limits_{A_{cs}} \frac{\eta_s \cdot (\vec{v} - \vec{v}_0)}{d(\vec{r})} dS \tag{23}$$

A_{cs} – surface of the component metallization
η_s – viscosity of the molten solder
$\vec{v}$ – speed vector of the component movement
$\vec{v}_0$ – speed of the point at d distance, which is 0 if it is on the pad, and not 0 if the point is on the surface of the molten solder
$d(\vec{r})$ – distance between the pad or the surface of the solder and the point under investigation, which is designated by the $\vec{r}$ vector on the A_{cs} surface

Consequently the net force (24) acting on the component during reflow soldering, is the sum of the above described forces and the gravity force:

$$\begin{aligned}
\vec{F}_{sum} &= \vec{F}_{st} + \vec{F}_p - \vec{F}_v + \vec{F}_{grav} \\
\vec{F}_{sum} &= \sum_i^{LS,LG,SG} \int\limits_v \gamma_i d\vec{l} + \int\limits_{A_{cs}} (\rho_s g \cdot h(\vec{r})) d\vec{S} + \\
&\int\limits_{A_{cs}} \left(\gamma_{LG} \left(\frac{1}{r_1(b(\vec{r}))} + \frac{1}{r_2(b(\vec{r}))} \right) \right) d\vec{S} \\
&- \int\limits_{A_{cs}} \left(\frac{\eta_s \cdot (\vec{v} - \vec{v}_0)}{d(\vec{r})} \right) dS + \int\limits_{V_{comp}} \rho_{comp} \vec{g} \cdot dV
\end{aligned} \tag{24}$$

2.2 Pilot experiment concerning component self-alignment

In our experiment the self-alignment of 0603 size (1.5 × 0.75 × 0.4 mm) chip resistors were investigated. The components were misplaced intentionally in x and y directions and θ offsets (0°, 10°, 20°) were applied as well. Usually the directions are defined in the case of misplacement as follows:

- x direction is parallel to the shorter side of the component,
- y direction is parallel to the longer side of the component.

The exact position of the SM resistors before and after soldering can be measured by the guidelines of the IPC-9850 standard. It advises placing fiducial points around the solder pads as it is illustrated by Fig. 10. In order to determine the position of the SM component the distance between the fiducial points and the corners of the component package should be measured.

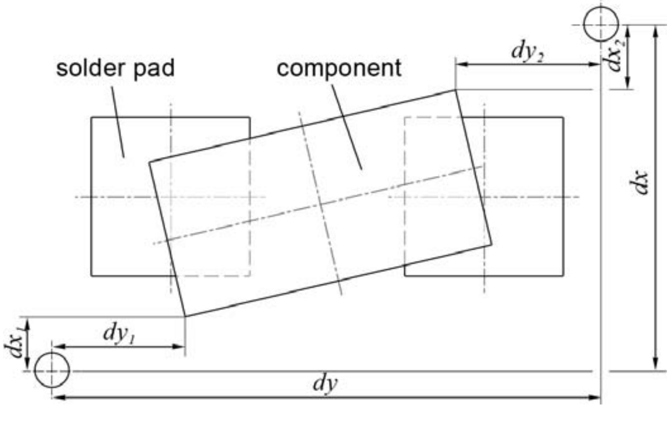

Fig. 10. Determining the position of the component

The x, y and θ offsets can be calculated by the following expressions (25):

$$\begin{aligned}
x_{of} &= \frac{dx_1 - dx_2}{2}, \quad y_{of} = \frac{dy_1 - dy_2}{2}, \\
\theta_{of} &= \arctan\left(\frac{dx}{dy}\right) - \arctan\left(\frac{dx - dx_1 - dx_2}{dy - dy_1 - dy_2}\right)
\end{aligned} \tag{25}$$

The placement offsets in x direction were 0 to 900 μm in 100 μm steps, while the y placement offsets were 0, 280 and 380 μm.

Lead-free (type 3, SAC305) solder paste and 150 μm thick, laser-cut, stainless steel stencil was used for the experiment; while the applied reflow profile is illustrated by Fig. 11.

By evaluating the results it can be said, that the self-alignment of chip resistors has occurred even in the case of 500 μm x direction misplacement. When large y direction- and θ offsets were applied, the self-alignment of components has occurred only in the case of lower x direction misplacement, as expected.

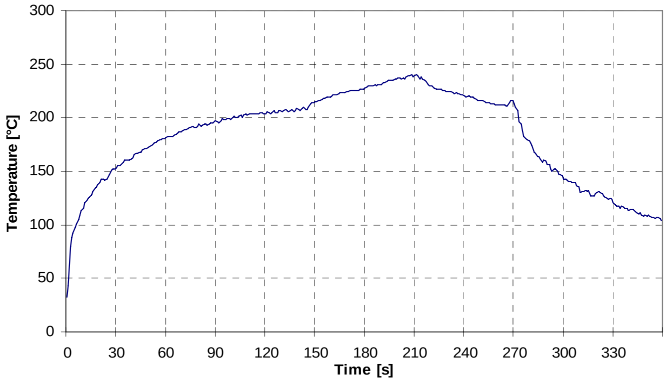

Fig. 11. Reflow profile of the experiment

Fig. 12 shows the x misplacement ranges (up to 500 μm) where self-alignment occurred with given y and θ offset parameters. Another observation can be stated on the base of the experiment, that the SM chip resistors have moved less distance in y direction than in x direction. The average distance which is travelled by the component in x direction is 249 μm, while the average distance in y direction is 75 μm. For an example position of five components before and after soldering is illustrated by Fig. 13.

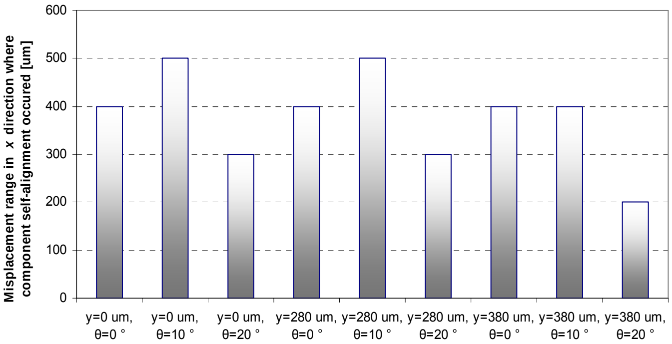

Fig. 12. Occurrence of component self-alignment in the case of different x, y and θ offsets

2.3 Confirmation of the experiment results by the three dimensional force model

The result of pilot experiment have shown that the SM chip resistors travel less distance in y direction than in x direction during reflow soldering. This can be explained by the three dimensional force model in the following way.

- In the case of x direction misplacement the forces originating from the surface tension of both solder joints aid the self-alignment symmetrically as it is illustrated by Fig. 14.

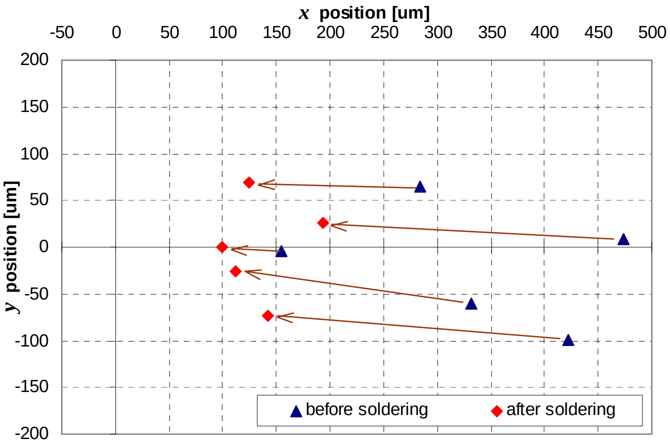

Fig. 13. Position of five components before and after soldering

- In the case of y direction misplacement the system is not symmetrical to its shorter side, the shapes of molten solders are different on the two faces of the component and the force due to hydrostatic pressure is greater on the face where the fillet of the joint is concave as it is illustrated by Fig. 15 ($F_{p1}<F_{p2}$). The solder on the right face of the component pushes the resistor out from itself and aids the y direction self-alignment. The forces due to surface tension are different on the two faces as well as the force originating from hydrostatic and capillary pressure. Unfortunately the forces on the two faces are opposite to each other therefore only the difference of them makes the resistor to move. This is the reason why the degree of resistor self-alignment is lower in y direction than in x direction.

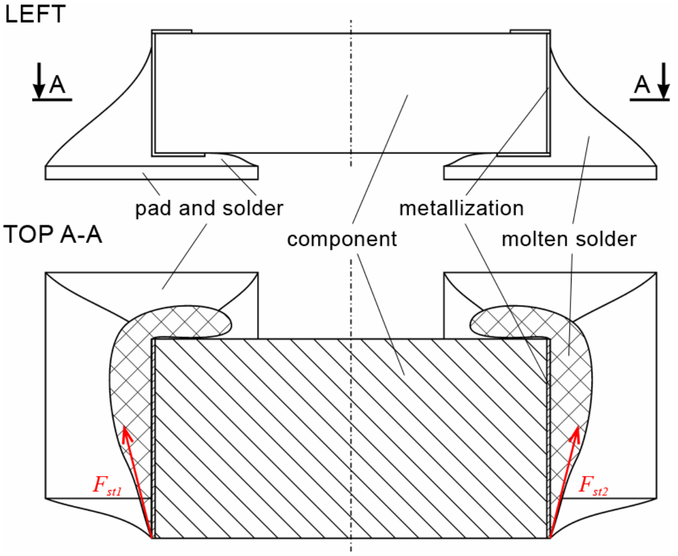

Fig. 14. Leftview and topsection of the system in the case of x direction misplacement

2.4 Proposing the shape of component metallization in order to improve y direction self-alignment on the base of the three dimensional model

It has been discussed in section 2.2. that if the end of the metallization is not reached by the liquid solder the contact angle is

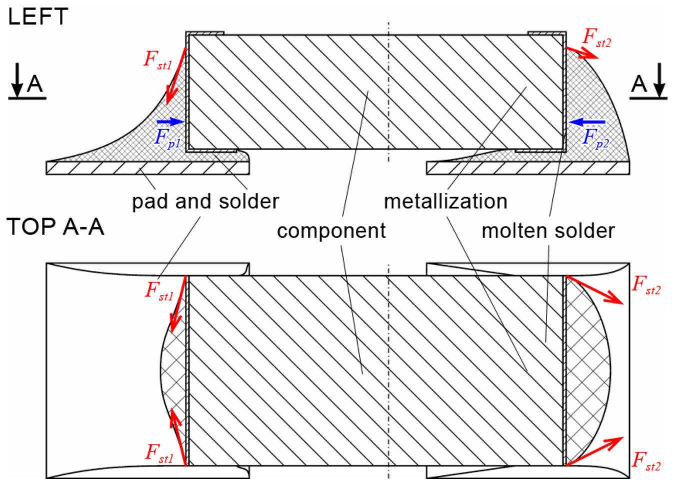

Fig. 15. Leftsection and topsection of the system in the case of y direction misplacement

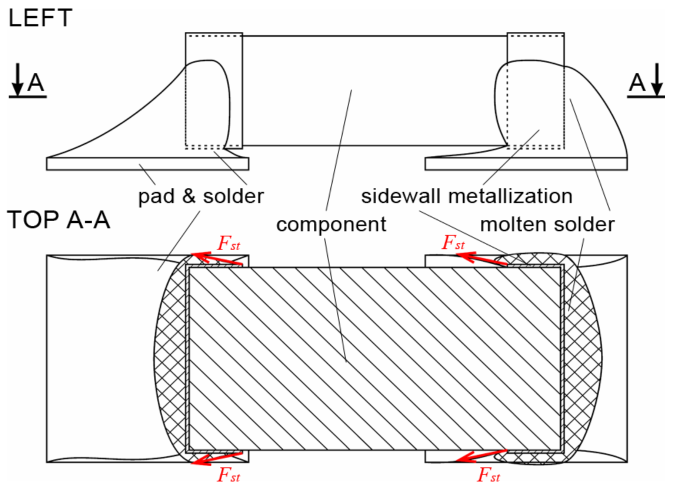

Fig. 17. The wetting angle in the case of different locations of metallizations

equal to the wetting angle, but in the case when the end of the metallization is reached by the liquid solder the contact angle depends on the volume of the solder. Besides even if the volume of the solders ($V_1 = V_2$) is equal the contact angle depends on the locations of the bodies (metallization) to be wetted as it is illustrated by Fig. 16 ($\theta_1 < \theta_2$).

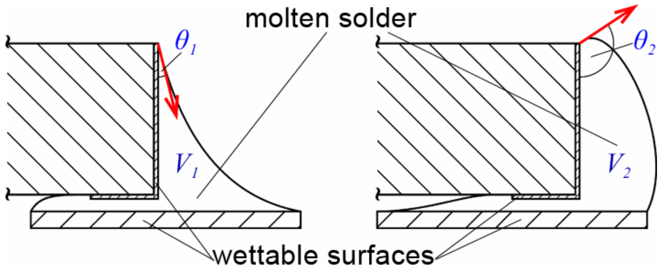

Fig. 16. The wetting angle in the case of different locations of metallizations

Therefore it can be predicted theoretically that if the metallization presents on the sidewalls of the component also the forces due to surface tension on the contact lines of sidewall metallizations will point to the same direction in the case of y direction misplacement (Fig. 17). The forces due to hydrostatic pressure will be formed as it is illustrated by Fig. 15. Naturally after some self-alignment, when the system is nearly symmetrical, the F_{st1} and F_{st2} forces will be opposite to each other.

Real experiment was made as well to prove that the degree of y direction self-alignment is larger if metallization presents on the sidewalls of the component according to the above described theoretical model. Two types of commercially available SM chip components (chip resistor and chip capacitor) were compared together from the aspect of y direction self-alignment. Both components are 0603 size (1.5x0.75 mm) but the chip capacitors have metallization on their sidewalls too in opposition to the chip resistors (Fig. 18). Since the chip capacitor is nearly three times heavier than the chip resistor (mass of capacitor is 3.2 mg, mass of chip resistor is 1.4 mg) the term of *specific displacement* [μm·mg] is introduced for better comparing, which is the multiplication of the component mass and the distance travelled by the component during reflow soldering. The components were misplaced intentionally in y direction by 200 μm and 400 μm. The positions of the components were measured before and after reflow soldering as well as in the pilot experiment and the same equipments were used too:

a.) b.)

Fig. 18. The components used for the experiment: a. chip resistor, b. chip capacitor

- Type 3, SAC305, lead-free solder paste
- 150 μm thick, lasercut, stainless steel stencil
- Same reflow profile as illustrated by Fig. 11
- 90 chip resistors and 90 chip capacitors were used for the experiment
- The results are averaged by 18 components.

By evaluating the results it can be said that the y direction self-alignment of chip capacitors with metallization nearly same as the proposed one is significantly better. The results are illustrated by Fig. 19, where the vertical axis is the specific displacement (the distance travelled during reflow soldering multiplied by the mass of the component) while the horizontal axis is the misplacement in micrometers before reflow soldering. The chip resistors are represented by the blue marks, while the chip capacitors are represented by the red marks. The distance travelled by the component is larger at both components in the case of greater misplacement. This fact can be explained by the symptom that the balance between the forces (F_h and F_{st}) forms later thus the deceleration of the component movement manifests later as well in the case of greater misplacements.

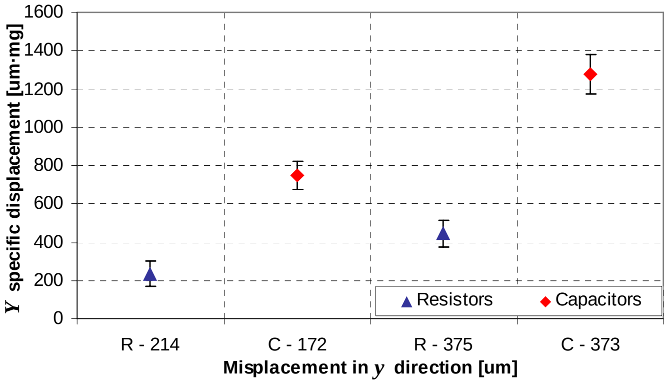

Fig. 19. The y direction specific movement of the components in the function of y direction misplacement

3 Conclusion

A three dimensional kinematical model has been created in order to describe the motion of SM chip components during reflow soldering. The self-alignment of chip resistors has been investigated by experiments. By evaluating the results it can be said, that the self-alignment of chip resistors has occurred even in the case of 500 μm x direction (lateral) misplacement. Another observation can be stated on the base of the experiment, that the SM chip resistors have moved less distance in y direction than in x direction. The average distance which is travelled by the component in x direction is 249 μm, while the average distance in y direction is 75 μm. The explanation by the kinematical model of that observable fact is that in the case of x direction misplacement surface tension of both solder joints aid the self-alignment, while in the case of y direction misplacement the system is not symmetrical to its shorter side, forces due to hydrostatic pressure and surface tension on the two faces of the component are opposite to each other therefore only the difference of them makes the resistor to move.

It has been proposed on the base of the kinematical model that if metallization presents on the sidewalls of the component then the y direction self-alignment of components can be improved. The proposal has been confirmed by real experiments as well. Surface mounted chip resistors and chip capacitors have been compared from the viewpoint of y direction self-alignment. The chip capacitor has a shape of metallization nearly the same as the proposed one. On the base of the results it can be stated that the y direction self-alignment of chip capacitors with metallization nearly same as the proposed one is significantly better. Hence the three dimensional kinematical model has been proved to be right, however in the future we would like to extent our researches by simulations.

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