

WAVE SOLDERING QUALITY IMPROVEMENT BY DESIGN OF EXPERIMENT APPROACH

Anna Andonova, Nely Dinkova, Ivan Marinov

Department of Microelectronics, Technical University of Sofia, 8 KL. Ohridski str., Bulgaria,
phone: +359 2 965 3263, ava@ecad.tu-sofia.bg

The investigation deals with quality improvement of wave soldering joints for printed circuit boards (PCB) by using DOE approach. Using DOE pro XL capabilities, DOE and statistic process control an effective way to approach and evaluate wave soldering process development is offered to determine the most essential control parameters in order to achieve the optimum process set-up for individual application. An example was given to show the procedure and results in using our investigations. The goal in the presented experiment was to reduce greatly the solder connection defects as bridges and poor soldering elements.

Keywords: Wave soldering process, Design of Experiment, Optimization

1. INTRODUCTION

Experiments are often conducted to determine if changing the values of certain variables leads to worthwhile improvements in the mean yield of a process or system. Another common goal is estimation of the mean yield at given experimental conditions [1, 2]. In practice, it is difficult to fit an accurate and interpretable model to the data, which can attain both goals. A certain manufacturer of assembled electronic circuit boards was suffering from severe quality problem in terms of high percentage of solder defects.[3]

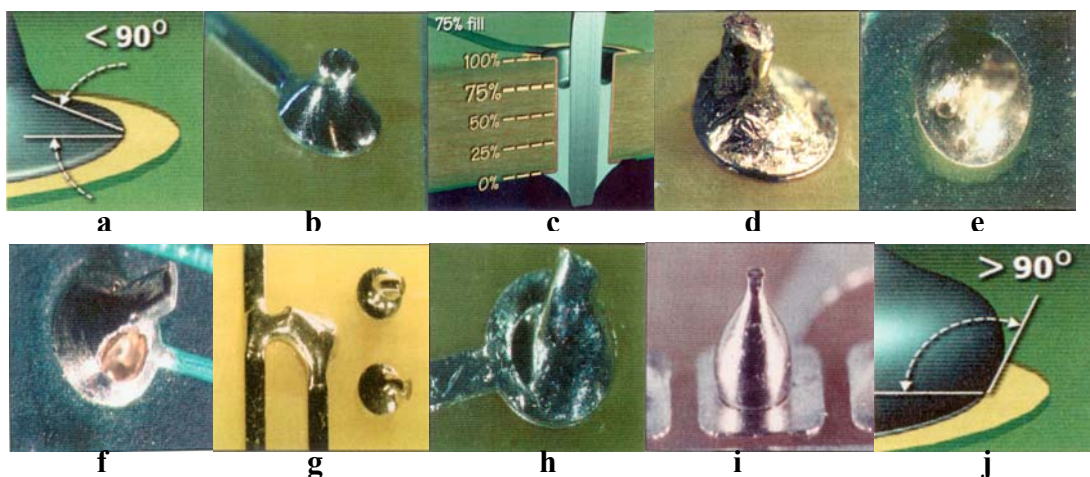
Design of Experiments (DoE) is widely used in research and development, where a large proportion of the resources go towards solving optimization problems [1, 4]. The key to minimizing optimization costs is to conduct as few experiments as possible. DoE requires only a small set of experiments and thus helps to reduce costs.

What has been lacking, however, are studies directly related to real-world applications and advice on such topics as procurement, design, processes, maintenance, inspection, etc. The completed PCB should be inspected for poor solder joints, solder bridges, stray wires, or other anomalies [4]. The wave solder process involves preheating, fluxing, soldering using a wave of solder, cleaning, and quality control. The process must be adapted according to the design (mass, size, component density, component type, etc.) of the circuit card to optimize quality, i.e. minimize solder connection defects. Process parameters which are controllable are the preheat temperatures and the line speed [5]. Circuit card manufacturers produce products of great diversity in small lot sizes, compounding the selection of good process settings. Manufacturers have relied on establishing process settings by trial and error or simplified analytic models based of experimental results [6].

In this report the investigations on wave soldering process quality improvement by DOE execution with using DOE pro XL capabilities are presented.

2. EXPERIMENT LAYOUTS AND DESIGN

The main factors influence on the wave soldering quality are the using boards and components cleanness, the availability of some flux and the flux type and amount, the components and solders preheating, the passing velocity of the placement boards and components through the machine, the wave type and level of the solder and the cooling solder time. The soldering quality depends also considerably on the crystal shapes formed during the solder cooling process, the temperature and time of metals warming up near the place of formed soldering joints, % content of different metals in solder and the solder supplemental components. Here are used four levels of soldering state: target, reasonable, process indicator and wave soldering joints defect. We consider a perfect soldering joint will fill 100% and wet 360° (Fig.1a, b) and the contact angle is less than 90° . The reasonable soldering is with 270% wetted or 75 % filled (Fig.1c). During visual inspection pore soldering joints (so called cold soldering) (Fig 1e, f), solder bridges (Fig.1g), poor soldering elements (Fig. 1h), no wetted solder (Fig. 1i) bad wetted solder with angle more than 90° (Fig. 1j), or other anomalies are noticed.



Фиг.1 Samples of inspected different types of wave soldering joints

A Pareto analysis of supplying PCB for electric trucks revealed (Fig.2a,b) that most of the defects occur due to bridges (i.e., short circuits between terminals). A sample of 1000 under standard production conditions has shown a defect rate of 9.9%, which was quite unacceptable to the customers. In order to rectify the above problem, it was decided to perform an experimental design with the objective of reducing the number of defects. DOE PRO XL was used for design of our experiment. It is an Excel add-in, which gives users powerful yet easy-to-use DOE (Design of Experiments) capabilities. From within Excel we are able to create designs, analyze designs using multiple regressions, plot results, optimize, and predict.

In using DOE PRO we was to create the design. Our design goal is to be improved the quality of PCB soldering manufactured by wave soldering process. The experiment was run on EconoPak[®] Gold machine of Electrovert in firm Curtis/Balkan (Fig. 2 c).

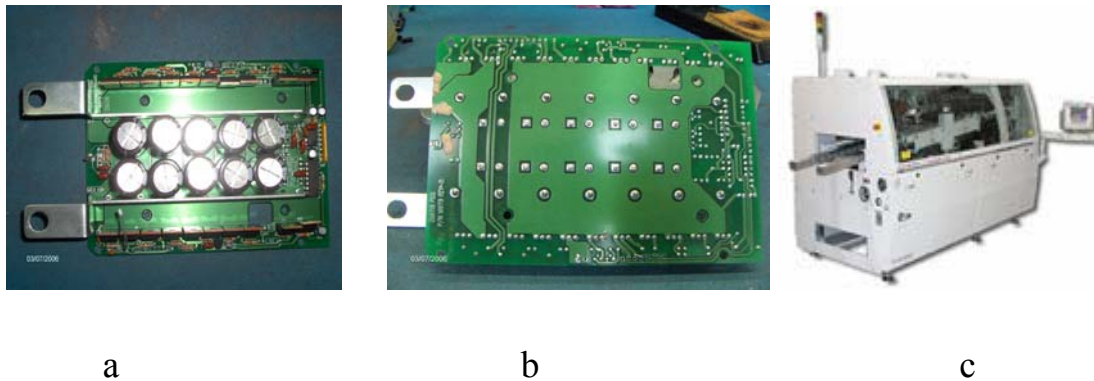


Fig.2. Front and back side PCB example – a and b, and a view of EconoPak[®] Gold machine - c

The solder paste used in the reported here experiment is 63% Sn, 37% Pb. Before embarking on the Design of Experiments described in this paper, we calibrated the used machine. Using the manufacturer's defined procedure, we verified that Cp and Cpk values passed the minimum 1.6 values. To reduce the amount of statistical "noise" we used the same machine, throughout the experiment. We also used the same substrate throughout, for measurement purposes.

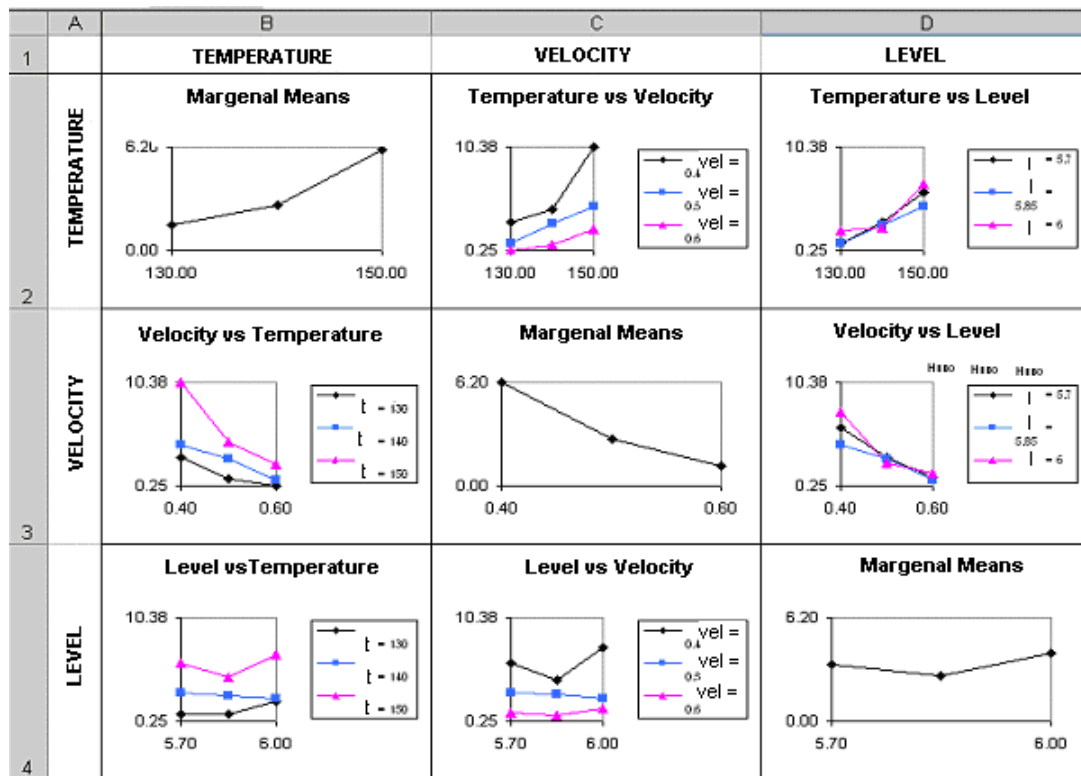
The factors that influence on the soldering quality are: the cleanness of the printed board and placed components, the type and quantity of the flux, the temperature of component and solder heating, the velocity of the saturated boards crossing machine, the level of the solder wave and the time of solder cooling. In this experiment only three factors will be included. Their minimal and maximal levels are shown in Table 1. During the experiment two answers solder bridges and no wetted solder respectively are checked

Table 1 DOE factors

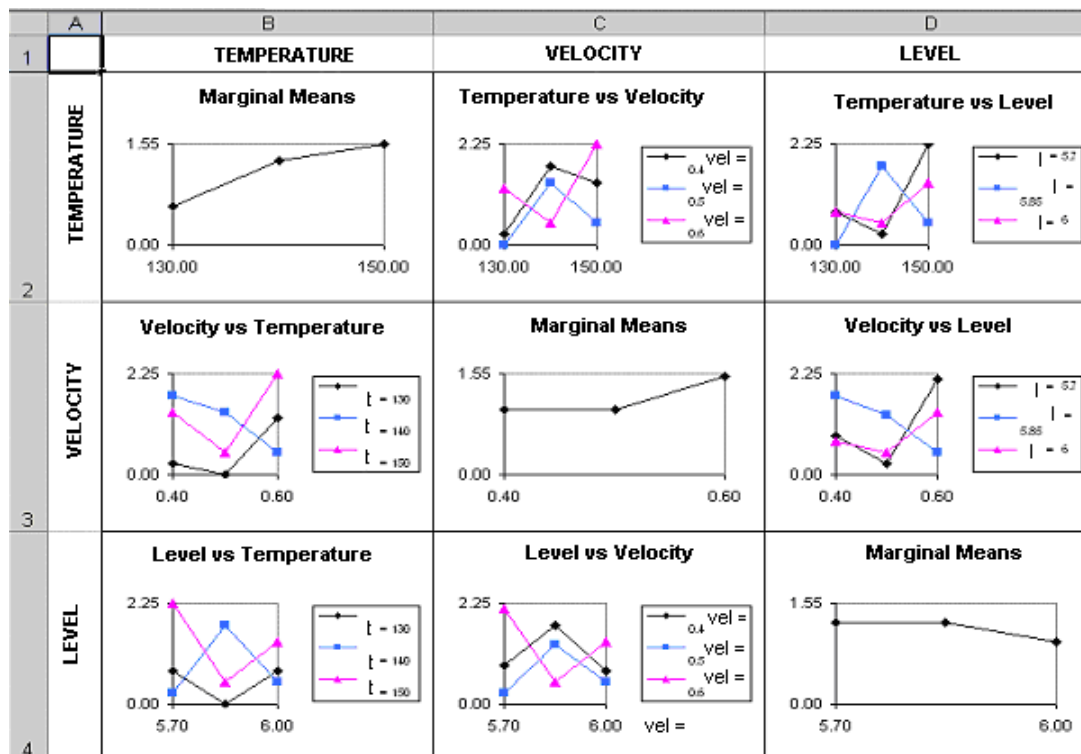
Factors	Low	High
Heating temperature, °C	130	150
Crossing velocity, inch\sec	0.4	0.6
Wave level, mm	5.7	6

3. RESULTS

To analyze the concrete state multitude of plots are used. On the Fig. 3a,b they are shown.



a



b

Fig. 3 Dependences between the factors

The surface diagram of the answer “solder bridges” for the factors “Temperature” and “Velocity” and the value=5.7 mm of the constant factor “Level” is shown in Fig. 4. The Contour plot is shown in the Fig. 5. The view of the Interaction Plot is shown in Fig. 6.

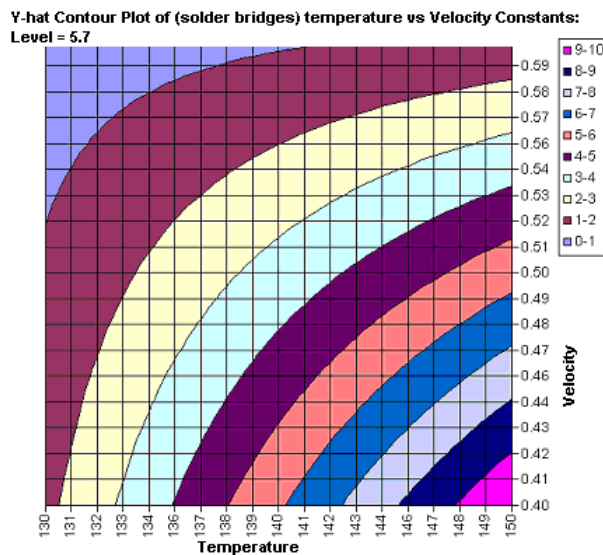


Fig. 5. View of the Contour Plot

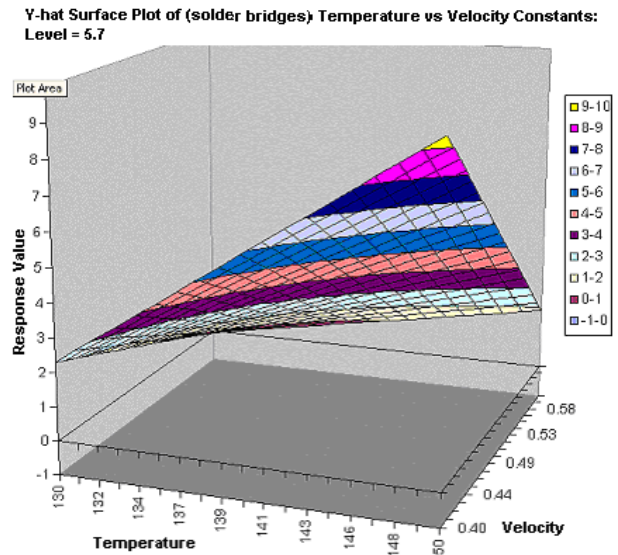


Fig. 4 View of the Surface Plot

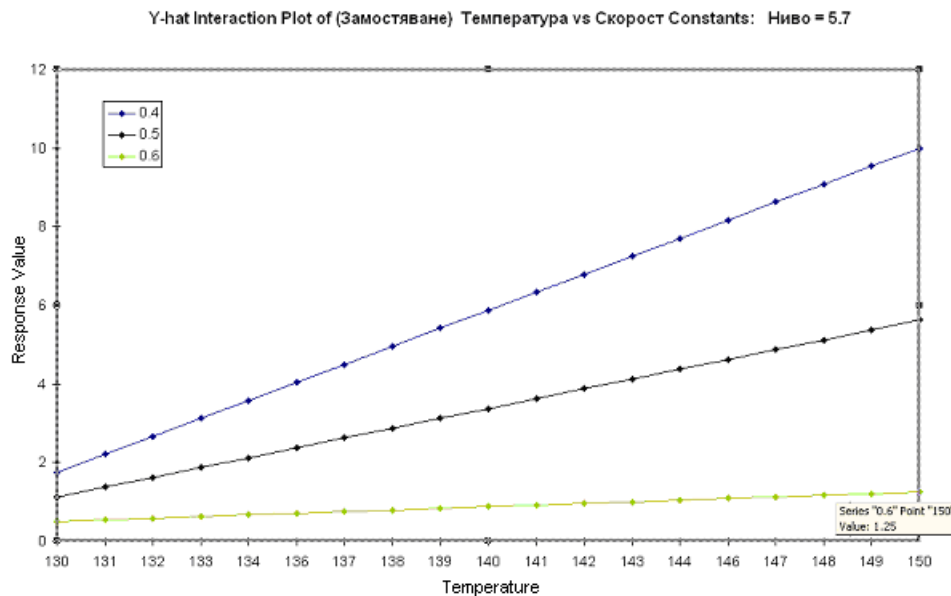


Fig. 6 View of the Response Value

The least solder bridges will be appeared for the velocity = 0.6 inch/sec, such as their number for temperature = 130°C is 0.5, and for the temperature = 150°C is 1.25. On the same way we can compose the plot of the solder bridges for constant factor “velocity = 0.6” and interaction between the two of other factors “temperature” and “Level” respectively. In this case it can be fixed zero solder bridges for temperature of 130.6°C and level of 5.85 as well for temperature of 133.7°C and level of 6.

The optimization of the design is the next step. The result of the optimization shows that for 48 from 50 repeats we have 0.5 solders bridges and for 43 from 50 repeats 0.25 no wetted soldering respectively. The multiple response prediction is shown in Fig. 7.

Factor	Name	Low	High	Exper
A	Temperature	130	150	130
B	Velocity	0.4	0.6	0.6
C	Level	5.7	6	5.7

Multiple Response Prediction				
	Y-hat	S-hat	99% Confidence Interval	
			Lower Bound	Upper Bound
Solder bridges	0.5000	0.8246	-1.974	2.974
No wetted soldering	0.2750	0.7909	-2.098	2.648

Fig. 7. View of Multiple response prediction

Table 2 Results of the optimization

Factor	A	B	C		Solder bridges			
Row #	Temperature	Velocity	Level		Y1	Y2	Y3	Y4
1	130	0.6	5.7		0	1	2	0
Factor	A	B	C		No wetting solder			
Row #	Temperature	Velocity	Level		Y1	Y2	Y3	Y4
1	130	0.6	5.7		1	1	0	0

4. CONCLUSIONS

In this paper the application of Macros Excel DOE PRO as an instrument for the quality of wave soldering joints improving is presented. The aim of the completed optimization was to decrease the number defects.

It is possible to examine the effects of numerous factors and to solve manufacturing problems of quality.

The design modification is possible. In such case we can change the names, the maximal and minimal values of the main effects, the number of experiments as well the type of interactions.

■

5. REFERENCES

- [1] Diepstraten G., V. Soltec, *Analyzing Lead-Free Soldering Defects in Wave Soldering Using Taguchi Methods*, Proceedings of Apex 2000, March 14-16, 2000, Long Beach, California, URL www.ipc.org
- [2] Through-Hole Solder Joint Evaluation Desk Reference Manual, IPC-DRM-40E.
- [3] Gevers M., X. Bombois, B. Codrons, G. Scorletti, and B.D.O. Anderson. *Model validation for control and controller validation in a prediction error identification framework - Part I: theory*. *Automatica*, 39(3):403–415, March 2003.
- [4] *The electronic Packaging Handbook*, Ed. Blackwell G.R., Boca Ration: CRC Press LLC, 2000.
- [5] *Thermal Design of Electronic Equipment*, Ed. Ralph Remsburg, Boca Raton: CRC Press LLC, 2001.
- [6] Andonova A., G. Mihov, N. Kafadarova, J. Potencki, *Design Optimization of Electronic Systems by DOE*, Proceedings IMAPS'2006, 24-27 September, Poland, 2006 (to be printed)