PARAMETER DESIGN TO IMPROVE YIELD IN INTEGRATED CIRCUIT ASSEMBLY PLANT.

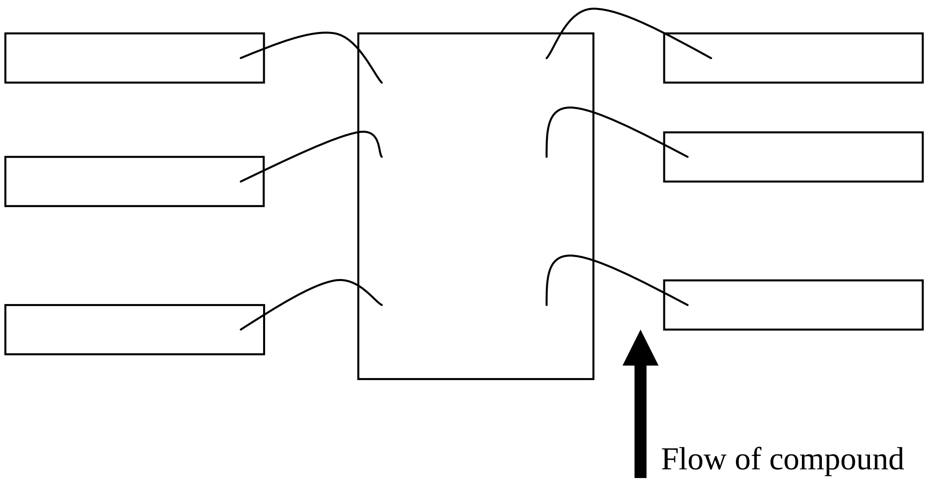
Rudy Wawolumaja [1])

Abstract

This paper describes design of experiment using Taguchi techniques in parameter design in improving yield performance of wire wash in PDIP (Plastic Dual In Line Package) assembling company. Taguchi approach applies statistical experimental design in the area of 'Off Line Quality Control' , that refers to the improvement of quality in the product and process development stages. Taguchi techniques in parameter design is used to improve process without eliminating cause of variation or noise factor.

Background of the problem.

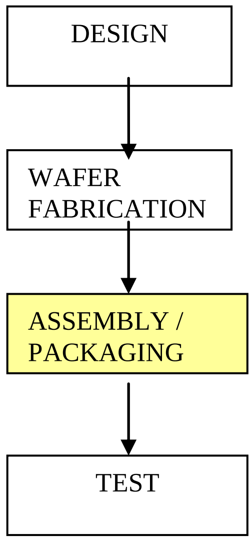
The case is applied to PT XYZ, which is a semiconductor packaging company in Indonesia. An assembling or packaging plant in semiconductor industry is a plant that processes the assembling of the IC chip on a metal frame, connects the circuitry of the IC to the pin of the frame and encapsulates it with Plastic (PDIP) .



This company run its business as a subcontracting company in PDIP (Plastic Dual In Line Package), its customers are mainly small size to medium size semiconductor

[1] Rudy Wawolumaja is a faculty staff in Industrial Engineering Department, Faculty of Engineering, Maranatha Christian University, Bandung .

producer in the USA, who market, design and fabricate Integrated Circuit chips, but do not have yet the economic scale to run the packaging plant, therefore they have to subcontract the assembly process. (even some of them don't have wafer fabrication, so they subcontract the wafer fabrication as well).
Manufacturing Chain of Semiconductor Industry :



In PDIP-IC component, the proportion of material cost of the component is 80% chip, 20% packaging, the proportion of the chip will be even higher in more dense chip or in LSI (Large Scale Integrated Circuit), which can be 90% chip - 10% packaging for 20 - 28 pin LSI , 95% chip - 5% packaging in 40pin LSI.
For this reason, the customer set a tight yield requirement to the packaging plant as the subcontractor. The customer gives yield off toleration of 3% of total packaging defect and if the yield off consistently exceeding 3%, the subcontractor may lose the business with that customer.

One of the most crucial processes is the molding / encapsulation process. One of the entity has to be controlled is the mold wash or wire wash. Mold wash or wire wash is the deflection of the wire due to the flow of the plastic during molding process.
If the wire wash is too large, it can cause the wire to touch the other wire or the lead frame. It causes short circuit between pins, which will be detected and screened out in the Open Short electrical test at the very end of the assembly process. This defect is not reworkable and late to be detected, in other word it will consume along the resources meanwhile they are scrap. Moreover, wire wash may cause reliability problem. When the distance between 2 wires is so close, near touching but not touching yet, the component may fail after hundreds hours of operation, due to the leak current melting the plastic in between. Wire wash defect contribute 0.8% of the total defect from the average 2% company total yield off.
To reduce variability in wire wash, experimental design is planned..

Taguchi Philosophy and Methodology in Parameter Design :

Taguchi developed a concept called the "Loss Function". From an engineering standpoint, the losses are those caused by deviation of product's characteristics from its desired target value.

To minimize losses, product has to be produced at optimal levels and with minimal variation in its functional characteristics.

The factors which affect the products functional characteristics are of two types :

a. controllable factors.

b. noise (or uncontrollable factors).

Controllable factors are those which can be easily controlled such as choice of material, cycle time, mold temperature etc. On the other hand, noise factors are those variables which are either difficult or impossible or expensive to control. Noise factors, in general are responsible for the deviation of the product's characteristics from its target value.

However, after identifying the most guilty noise factors, it is **NOT** to control the noise factor, since controlling noise factors is very costly if not possible. Instead we should try to select values for our controllable factors such that the product (or process) is least sensitive to the changes in the noise factors. In other words, instead of finding and eliminating causes (as the causes are often noise factors), our intent is to remove or reduce the impact of the causes or in Taguchi's terminology is to achieve robustness against noise factors. This activity is defined as 'Parameter Design' one of Dr. Taguchi three defined off line quality control activities.

The 3 steps involved are Systems Design, Parameter Design and Tolerance Design. System Design is basically non-statistical in nature. It involves innovation and requires knowledge from the field of science and engineering. It includes selection of the materials, parts and tentative product parameter values and the selection of production equipment and tentative values for process factors. The tentative nominal values are then tested over specified ranges and the best combination of levels is determined.

Parameter Design determines the product parameter values and the operating levels of process factors which are least sensitive to change in environmental conditions and other noise factors. This is the key step in achieving high quality without increase in cost.

Finally, Tolerance Design is employed if the reduced variation obtained through Parameter Design is not sufficient. It involves tightening tolerances on product parameters or process factors whose variations impart large influence on the output variation. In other words tolerance design means spending money-buying better grade materials, components or machinery.

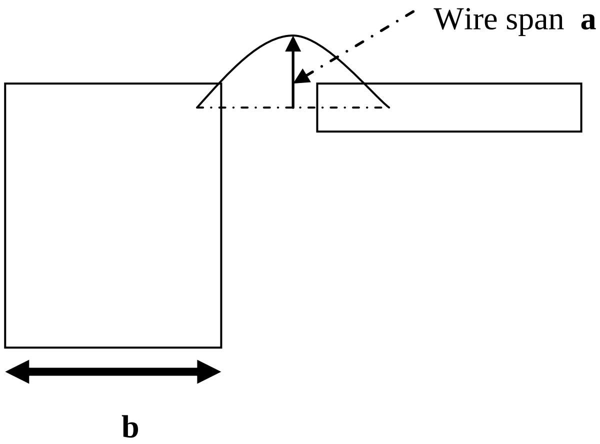
Most of the common mistake is to jump from Systems Design to Tolerance Design, ommiting the step of Parameter Design, where the most gain in term of cost and quality is obtained. Parameter Design is the step which the Japanese do so well.

Planning of the experimental design.

Step 1. Statement of the problem.
Variability in wire wash in plastic encapsulation of PDIP component.

Step 2. Objective of the experiment:
To identify the optimum configuration of factors in reducing wire wash.
To increase yield and reliability performance as consequence of wire was improvement.
To do the experiment by the least cost .

Step 3. Quality characteristics & measurement system.
The wire wash characteristic will be determined by measuring the deflection of the wire from original path as seen from upper side of the package. Since the wire is encapsulated by plastic mold the measurement is done using X-ray measurement to capture the magnified image.



The dimension of the deflection can be deducted from the ratio of a/b x actual length of b.
a is the magnified deflection as measured by ruler.
b is the magnified length or width of the chip as measure by ruler.
The actual length of b is known.

Step 4. Select the factor that may influence the selected quality characteristic. This is done by conducting brain storming session with process engineer in charge of molding operation and the process before molding (front end process).

From the brain storming session, the factors which determine the amount of wire deflection are as following:

- Molding compound :	- supplier	(1)
	- age	(2)
	- lot #	(3)
- Mold condition :	- Mold design	(4)
	- Mold age	(5)
- Mold parameter :	- slow close height	(6)
	- slow close time	(7)
	- cycle time	(8)
	- clamp pressure	(9)
	- transfer pressure	(10)
	- mold temperature	(11)
	- preheat temperature	(12)
- From lead bond process :	- bonding loop height	(13)
- From bonding configuration:	- wire span	(14)
	- wire position to flow	(15)

From the brain storming session, there are 15 factors may influence wire wash.
After conducting the brainstorming session, further study to the process are necessary for deciding the control and noise factors.

Step 5. Identifying those factors into control and noise factors.

5.1. Analysis of control factors.

Control factors are the factors that are easily adjusted or under our control to change. The aim of this experiment is to look for level of the control factor to get the robust design.

The molding parameter is the easiest factors to change and control, so the relevant parameters for wire wash are chosen as the control factors. The determination of relevancy of the factors requires knowledge of the process. The knowledge is acquire from the characteristics of the molding compound and the physical and chemical mechanism involved.

The mold parameter of clamp pressure is excluded from the control factor, since from process knowledge this parameter will affect only plastic bleeding defect and not wire wash..

There are 6 control factors identified :

-slow close height
-slow close time
-cycle time
-transfer pressure
-mold temperature
-preheat temperature.

5.2. Analysis of noise factors.

Noise factors are those factors that are difficult to control or very expensive to control or impossible to control and it changes during the process.

There are 7 noise factors identified :

- plastic compound supplier
- plastic compound Lot#
- plastic compound age
- Mold design
- Mold age
- bonding loop height
- wire span

- Supplier:

  The company has three plastic compound supplier, i.e. : Plaskon, Nitto and Sumikon. Although the company set the same specification in the Material Procurement Specification and set the same Incoming Quality Control procedure. It is very likely that there will be variability between supplier.
- Plastic compound Lot # :

  Different lot# within the same supplier is considered as source of variability as well.
- Plastic compound age:

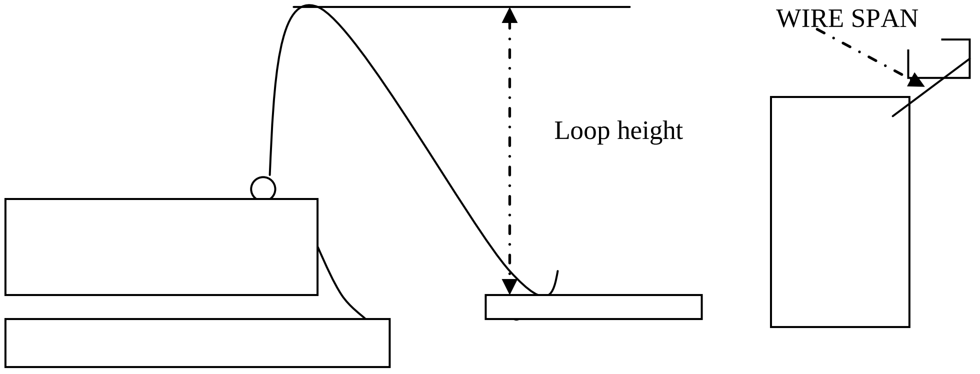
  The type of plastic compound is thermosetting type, temperature and time will transform the state of the plastic to the setting phase, which is irreversible. In other word the compound will react or change by time or function of time. Therefore the plastic compound has a shelf life and has to be stored under a controlled cool storage with maximum temperature of 2 degree Celcius to restrain the change of state process. However there will be some differences of characteristics vs age of compound, which is the source of variability.
- Mold design :

  The mold design may give different result of wire wash for different location in the mold. The best design will be the mold which has uniform distance from cull to every units molded.
- Mold age :

  The age of the mold may affect the wear out of the gate, the gate prevent the mold from filling the unit, before the whole runner is filled in with fluid plastic. Therefore there might be differences between different mold age with respect to the wire wash.
- Bonding loop height.

  The bonding loop height is the parameter from lead bond process, which is subjected to variability.
- Wire span :

  Wire span is determine by the product type or the chip being processed.



Step 6 Select levels for factors :

Ross (1989) suggest that for screening experiments, the number of levels should be kept low, two levels if possible.

For controllable factors, since this is an initial screening experiment, all the controllable factors is planned to run on 2 level, the high and low value of the upper and lower limit of the process specification.

Comment :

As a matter of fact, it is recommended to use a 3 level setting where possible. Because with only a 2 level setting, we have no choice but to assume a one-directional relationship with no maximum and minimum, in addition to that we have to assume linearity. However if we are confident about linearity 2 level settings will be adequate.

A 3 level setting allows for the possibility of a change in direction with the response variable exhibiting a maximum or minimum as the variable level is changed. The only way to test for curvilinear relationship is to test at 3 levels.

For noise factors, it is common sense not to select levels more complex than the controllable factors, so 2 levels will be most appropriate for noise levels for our case.

Step 7. Identify control factors that may interact.

From the knowledge of the process time and temperature may interacts. (see picture viscosity vs time at various temperature).

There are 2 factors related with time :slow close time & cycle time and 2 factors related with temperature, i.e.: mold temperature and pellet preheat temperature. This would give 2 X 2 = 4 combination of interaction (1st level), ie. :

1. slow close time interacts with mold temperature.
2. slow close time interacts with preheat temperature.
3. cycle time interacts with mold temperature.
4. cycle time interacts with preheat temperature.

Step 8. Select the orthogonal array.

There are 6 controllable factors each at two levels this will give 6 degree of freedom and 4 interactions.

L8 OA will be the most efficient array to use for our case, L8 OA provides 7 degree of freedom, so for our case L8 gives 7-6 = 1 degree of freedom left for interaction between factors.

L16 OA provides 15 degree of freedom and for our case L16 OA gives 15 - 6 = 9 degree of freedom left for interaction between factors.

Repetitions for trial has to be determined to assess the noise effect. The larger number of repetition gives better assessment of the noise effect. However the choice of repetition is trade-off between accuracy and cost or practicality.

A better parameter design strategy would be to use an inner array for control factors only and outer array for noise factors only. The idea behind that is to deliberately create noise to identify the controllable factor levels that are least sensitive to it.

Since there are 7 noise factors identified in our case, it is very unlikely to assign all the factors to the outer array. The realistic approach would be to identify the most dominant noise factors to the wire wash and to assign those factors to the outer array and the rest noise factors to randomization. For our case L4 OA for the outer array is appropriate, it means 4 repetition for each trial and 3 noise factors to be assigned (3 degree of freedom).

After further investigated by the process engineer and manager and based on the experience and engineering intuitive of the engineer and person who is daily in charge with the process, it was decided that from the 7 noise factors, the three factors that affect wire wash most are :

1. Bonding wire span
2. Plastic compound age
3. Bonding loop height.

These factors are selected as the noise factors for outer arrays.

The level 1 is low level for wire span, that can be selected from the bonding sheet (every product type has bonding sheet, that determined which frame to use, which bonding pad to be wire connected to which lead tip of the frame). Level 2 is the high level of the wire span. Both level will be specified before the experiment, by selecting which product type to be used.

For plastic compound age level 1 represents low age and level 2 represent high age or old age.

For bonding loop height, level 1 represents the low loop height and level 2 represents the high loop height, both are within the allowable spec limit.

To induce these noise factors into the experiments, selection and identification of the product type and each particular unit, plastic compound has to be done by the experimenter.

Using L8 OA for the 6 controllable factors (inner array) and L4 OA for the 3 noise factors (outer array) gives 8 x 4 = 32 experiments.

Using L16 OA as inner array and L4 OA as outer array gives 16 x 4 = 64 experiments.

Ross 1989, suggests to select the size of the experiment based only on factors and if there are any columns available afterward then assign these to an interaction of interest.

The suggestion implies to use the L8 OA, hence the choices which one from the 4 interactions has to be decided. Again the decision has to be based on process knowledge, at this stage information, technical expertise of plastic compound manufacturer may be very helpful.

<u>Comment on Ross Sugestion :</u>

As a matter of fact; the Taguchi approach is designed utilising the knowledge of the person running the experiment. The persons 'knows' (non statistical conclusion) which interactions may not be significant prior to the

experiment. In other words, the user will have already determined which variables are interacting, meanwhile with Classical Design of Experiment the analysis itself will determine what interaction are.
If the engineer / experimenter knows based on engineering or experience knowledge, that there are interactions between factors, the interaction should not be ignored.

Step 9: Assign factors and interactions into columns.

Suppose the choice is on the interaction of slow close time and mold temperature, then slow close time is to be assigned as the factor A in the 1st column of the OA and mold temperature as factor B in the 2nd column of the inner L8 OA. The interaction ab will be in the third column, and the rest of the factor in the 4th-7th columns.

A = slow close time	1st column.
B = mold temperature	2nd column.
ab = interaction of AxB	3rd column.
C = slow close height	4th column.
D = cycle time	5th column.
E = transfer pressure	6th column.
F = pellet preheat temperature.	7th column.

The inner array of L8 OA will be :

Col	1	2	3	4	5	6	7
Trials	A	B	ab	C	D	E	F
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

The outer array has 3 noise factors of :

1. Bonding wire span represented by X
2. Plastic compound age represented by Y
3. Bonding loop height represented by Z

The arrangement will be:

L4 OA outer array

Z	1	2	2	1
Y	1	2	1	2
X	1	1	2	2

Our Inner/Outer Orthogonal Array is

								L4 OA outer array			
							Z	1	2	2	1
							Y	1	2	1	2
							X	1	1	2	2
									Data		
Col	1	2	3	4	5	6	7	y1	y2	y3	y4
Trials	A	B	ab	C	D	E	F				
1	1	1	1	1	1	1	1	*	*	*	*
2	1	1	1	2	2	2	2	*	*	*	*
3	1	2	2	1	1	2	2	*	*	*	*
4	1	2	2	2	2	1	1	*	*	*	*
5	2	1	2	1	2	1	2	*	*	*	*
6	2	1	2	2	1	2	1	*	*	*	*
7	2	2	1	1	2	2	1	*	*	*	*
8	2	2	1	2	1	1	2	*	*	*	*

Step 10 : Conduct the test.

Thirty two experiments is conducted, following the the designed outer and inner Orthogonal Array, the X, Y, Z noise factor are forced, for example for trial 1 data y1 level A = 1, B =1, C=1, C=1, D=1, E=1, F=1 and the level of noise factor X=1, Y=1, Z=1.

Step 11 : The Analysis.

Signal To Noise Ratio (S/N ratio)

Taguchi has worked out three formulas for S/N ratio depending on the requirement for the response variable.

1. The higher the better

Formula : $S/N = - 10 \log 1/n (\Sigma 1/Y_i^2)$

2. The lower the better

Formula : $S/N = - 10 \log 1/n (\Sigma Y_i^2)$

3. Nominal is the best

Formula : $S/N = - 10 \log 1/n (\Sigma X^2 /S^2)$

In all 3 above cases, parameter optimization is carried out by choosing the levels with the highest S/N Ratio.

In our case of wire deflection, the lower deflection is the better, therefore the formula to use is :

$$S/N = - 10 \log 1/n (\Sigma Y_i^2)$$

There are several tools to analyse the results of experimental trials; they are :

- S/N Response Diagram.
- Half Normal Plot.
- Analysis of Variance (ANOVA).
- Numerical Test of Homogenity for mean squares.

<u>- S/N Response Diagram.</u>

The response diagram provides better visibility, Y axis represent response of S/N ratio and X axis shows various levels of each factor. To draw response diagram, first response table is to be created.

In response table, the columns represent the factors.
the rows represent the levels.

For each column, the row (level) with the highest S/N ratio is the optimum level. The greater the difference in S/N ratios within a column, the greater the significance of a factor. On the other hand, if all the levels for a particular factor give approximately equal S/N ratio, that means the factor has little significance.

- Half Normal Plots.

Half Normal Plot is similar to a full normal plot, but uses absolute values of the effects / contrast and uses half parts / scores of the full normal graph paper.
Effects / Contrasts which are comprised of random variation would cluster on a straight line through the origin, meanwhile effects which are significant will lie apart from the straight line.

Analysis of Variance (ANOVA).

Anova is performed to test whether the results are truly significant or they are risen because of sampling variability. MSS (Mean Sum of Square) of factors are compared with residual variation. Using F test, the significant effect of the control factor can be concluded.

Test of Homogenity for Mean Squares.

This test utilise Chi-square test, it evaluates and test mean square under null hypothesis of no real effects. The test uses mean and standard deviation of mean squares between the mean squares, one or more of the larger mean squares may be deleted and the test repeated on the remaining factors until a insignificant result is obtained. Then the remaining mean squares are put together to give an estimation of residual for testing the larger mean squares.

Step 12: Confirmation Run.

The analysis gives the optimum design, however in Taguchi experimentation there are possibility of an unexpected / unanticipated interactions between factors or wrong assumptions on linearity relationship in factors instead of curvilinear relationship. Therefore confirmation run is to be run to check for any difference between the run with the theoretical calculated value from the experimentation results.

Step 13: Drawing Conclusion on the experiment.

If the confirmation shows the validity of the experiment result, and the objective of the experiment has been met, the robust design is to be implemented and phase proceeds to documentation phase. This is to issue Engineering Change Notice on the process parameter specification and to document the experimental-design , analysis and results.
If the confirmation run confirms invalidity of the experimentation results, reiterate to step 4, there might be control factors or interactions between factors that are overlooked or wrong assumption on linearity instead of curvilinear relationship.
If the confirmation run confirms the validity of the experiment, but the objective of the experiment has not been satisfactorily achieved or in other words if the reduced variation obtained through Parameter Design is not sufficient, then Tolerance Design is to be employed.

Statistical Process Control Techniques to monitor improvement.

The main purpose of SPC is to monitor process and to detect any assignable change occured in the process, so that corrective action can be taken. The real SPC is to eliminate assignable causes of variation and deteoriation of process before defects happen; in this case variable control chart is the most appropriate to use.

SPC techniques can be used to ascertain whether or not an improvement has actually occured after the implementation of the robust design from the experimental work. For that purpose, base-line data of the performance of wire wash before the implementation is required. If SPC control charts to monitor wire wash has not been implemented, then SPC control charts has to be run for some period before the implementation of robust design to get base line data for comparison. It would be best to plan and do it during the experimental-design planning phase.

In our case, there are two best points to monitor the performance of wire wash.

First point is at moulding process. Samples of 5 units after moulding process are taken to be X-rayed on regular basis. Measurement is done on the predetermined lead or pin number. For this the best chart to be utilised is variable chart - Shewhart X-bar R chart. It is very unlikely to use attribute charts here, because the defect levels are pretty low , approximately 0.8%. To detect defect, sample size taken has to be sufficiently large to be X-rayed, which is unpractical and unrealistic. Using Shewhart chart, improvement can be monitored in term of shifting of the mean value to the smaller value and the reduction of the variability as well. The best measurement is the improvement of Process Capability Index.

The second point is at open short test. Open short test is 100% electrical test to screen out electrical open circuit and electrical short circuit. The reject units of that operation are collected. The percentage of defect from total can be derived by dividing the number of defect / number of units tested. From those defect units, samples are taken to be failure analysed. The result of the failure analysis can be used to estimate the contribution of wire wash to the total open short test. Then the result is plotted into a graph to see the trend. This graph can not be included in any SPC chart, however it can be used to monitor defect.

Summary :

Taguchi's methods, which is known also as quality engineering is a powerful and cost effective tool for producing quality. The heart of Taguchi's quality engineering system is known as Parameter Design, helps process resist variation from noise factor.

This method is the bridge between intuitive and instinctive engineering approach and the solid / rigid sophisticated statistical tools of classic design of experiments techniques. This method is getting its popularity for engineers to use, since it allows engineers to use their engineering instinct and intuitive and to utilise their engineering knowledge in designing experiment, so the experiment can be run in the most cost effective way.

References :

1. Aspinwall E., ‘Class Notes, Handouts MME 903 (1996)’, Univ. of Birmingham, School of Mechanical & Manufacturing Engineering/
2. Ross, PJ. (1989), 'Taguchi Techniques for Quality Engineering', Mc Graw Hill Book co.
3. Byrne,DM and Taguchi,Shin (1987) 'The Taguchi Approach to Parameter Design' , Quality Progress December 1987, p19-26.
4. Launsby, RG (1994), 'Taguchi or Classical Experiments', Quality/April 1994 p55-57.

APPENDIX 1.
Process flow of PDIP assembly / packaging plant.