ETM
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Title: How to Reduce Height Variation of the Manufactured Ink Stix to Gain Cost Competitive Advantage

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Abstract: This report describes the use of Total Quality Management techniques to reduce the variation of the height of ink cartridges (stix) in Tektronix color printers

How to Reduce Height Variation of the Manufactured Ink Stix to Gain Cost Competitive Advantage

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Tektronix

Phaser 350 Printer Ink Stix..

How to Reduce Height Variation of the Manufactured Ink Stix to Gain Cost Competitive Advantage

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A report submitted
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EMGT 560/660
Total Quality Management

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EXECUTIVE SUMMARY

For purposes of applying the principles of Total Quality Management, five student participants formed a project team to evaluate the variances in height of the ink cartridges (also known as stix) that are manufactured by Tektronix for printers. We applied quality improvement strategy as described in the Continuous Quality Improvement Project Manual copyrighted by Horizon Management Group, a division of Pinnel/Busch, Inc.

Specifically, the problem was known to exist but was difficult to pinpoint the cause or causes. Our team completed a plant visit and began an educational process as to the manufacture, process and operator influences that could affect the quality of the final product. Research was performed to gain as much information as possible, including previously tried methods. And as many causes as reasonable were identified using brainstorming and experienced engineering insight. These causes were then placed in a grouped association way on a cause and effect diagram. These relationships led to the design of a data collection sheet and according measurement plan. Data on these batches of stix were collected and statistical analysis was performed which resulted in the establishment of a baseline.

We observed that uneven temperatures around the nozzle areas could cause problems. Also that possible leakage could cause discrepancies. Countermeasures were designed to test these observations. The first countermeasure was to add insulation at key points of nozzle exposure to air temperatures. The second one was to add "o"-rings to decrease nozzle leakage.

Results of adding insulation were observable in the data recorded after the fourth batch. Although the stix products were in compliance, data showed better consistency. Adding "o"-rings to the existing insulation showed improvemenmt also as evidenced by the data obtained from the fifth batch. These results encouraged Tektronix to add a fuller "jacket" of insulation around the nozzle equipment.

The value of this study:

* Tektronix is happy to have a quality baseline in place for their "stix" products.

* A reduction in "out-of-compliance" stix occurs resulting in fewer jams of the feeder mechanism of the printer and therefore reduced waste of customer time.

* Stix cool at a more even rate. Stix that cool too fast can be brittle and break, which causes customer dissatisfaction.

* Consistency of nozzle standards has improved and creates added product consistency.

* Portland State University Engineering Management Program (EMP) graduate students have applied Total Quality Management skills to an actual problem occurring at a local company - Tektronix.

* The EMP students and Tektronix worked together to achieve results.

SECTION 1.

INTRODUCTION

1. A. Who is IQIT?

In our first meeting on January 10, 1997, we spend approximately two hours to get to know each other and familiarize ourselves with each other's.

We realized that forming a team can be difficult. Combining the cultures of four countries, two generations, and a wide range of experiences is an exciting and sometimes a challenging process. We all truly believe that a good team is the one that has good communication, forms a strong trust amongst the team member, clearly understand every team member's strengths and weaknesses. We think that what makes a winning team is how well you can optimize your team member's strengths rather than focusing on the weaknesses.

At the end, we formed what we call is "IQIT" team which stands for International Quality Improvement Team. We are aware of the fact that our team name sounds like "I quit"; however, deep inside we all knew that we were dedicated to learning.

Here is what we learned as a IQIT team.

1.B. Project Selection

Since we had quite a wide range of experiences, there were numerous ideas for the project. In our second meeting, everyone was asked to bring a proposal of their perspective projects.

On January 18, 1997, IQIT team met once again to decide what project to work on. The following criteria were followed:

a. The project has to represent a "real life" problem,
b. The project life (start to finish time requirements) must fit into our time constraints,
c. The company has to be willing to support the project,
d. The company should be logistically located,
e. The company also has to be open enough to share their knowledge and experience,
f. The company should also be willing to review our recommendations, and act upon it if supported by the data,

One of the projects was declined since the information was not easily accessible, while another project was rejected due to time constraints. Finally, after considerable debate on all the proposed projects, we decided to pick the project proposed by Dawn Greenwell of Tektronix Inc.

SECTION 2.

PROBLEM DEFINITION

GOAL: To characterize and optimize the ink stix packaging process by determining the source of the height variations in the manufacturing process.

PURPOSE: Reduce the variation range in the ink stick mass. Establish a statistical control method to ensure that the ink stick height and mass is maintained within specifications.

With each generation of new printers, the specifications for ink sticks become tighter and tighter. The current molding process is well with in specifications for the current production of ink stix, however the sources of variation had not been identified. Management felt that it was important to identify the sources of the variation now to better understand the process and anticipated the need for tighter specifications in the future.

Another benefit would be the ability to optimize the use of the ink by setting the process closer to the lower end of the specifcations. This would then create more ink stix and increase profits. However, management did not want to risk quality for a few more dollars, unless it was proven that all ink stix would fall into specifications.

After brainstorming with management, it was decided to concentrate on Phaser 340 ink stix. With the new marketing stategy, free black with every color ink stix purchase, Tektronix was producing four times as much black ink as any other color. This meant a higher availabilty for sampling of ink stix batches. With the ink identtified and condidentiality statements signed the IQUIT Team began the project.

SECTION 3.

APPROACH

3.A. Visit to Tektronix

We all agreed that it is utmost important to visit the company, see the process, talk with the key engineers who were most knowledgeable about the process.

Dawn arranged the meeting at the Tektronix Inc. After signing confidentiality agreements, IQIT team had a four hour visit at Tektronix on January 31, 1997. The visit was extremely informative and thought-provoking.

Our visit to the ink manufacturing plant at Tektronix Inc. allowed us to observe and learn design and product specifications, engineering methods, design practices, manufacturing techniques and equipment, materials handling, packaging, and quality inspection techniques.

3.B. Flow Diagram of the Ink Stix Manufacturing

Ink stix manufacturing can be viewed as two separate processes:

1a. Batch Process

Due to the confidentiality agreement, we can not give neither a detailed description of the process nor the schematics of the process. However, considering that the reader will need to have a basic understanding of the process, we would like to present the following basic schematics.

The phase change ink is made of several raw materials and dye. These ingredients are mixed together to create an ink with constant spectral strength and viscosity. This ensures constant print quality from the printer.

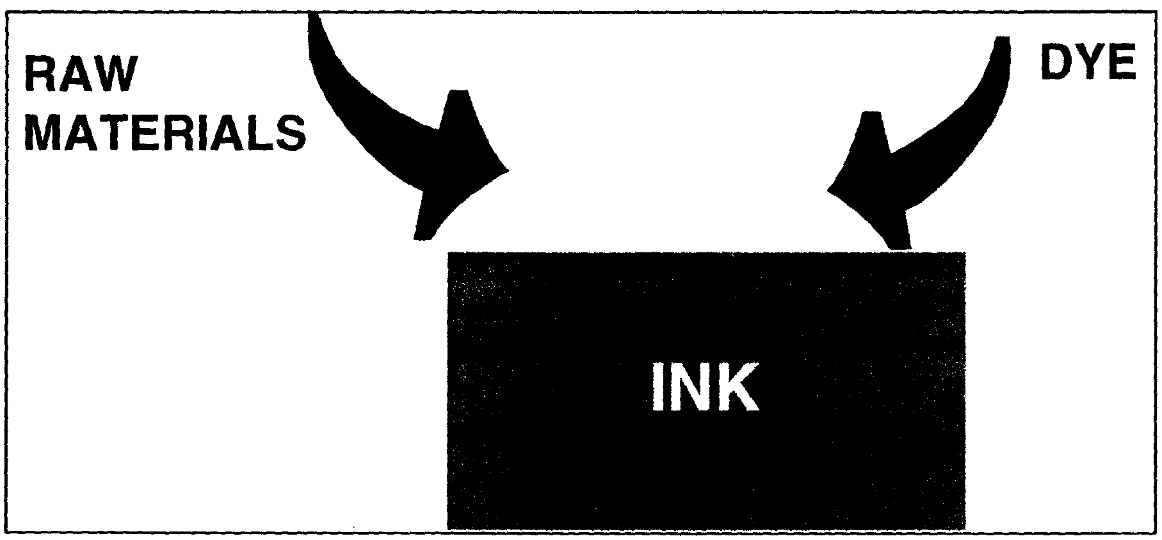

Figure 1a. Basic process flow diagram -Batch Process

1b. Packaging Process

The packaging process begins with the forming of the ink stix tubs. Next, the ink is poured into the tubs. In the finel step, the tubs are sealed and placed into boxes.

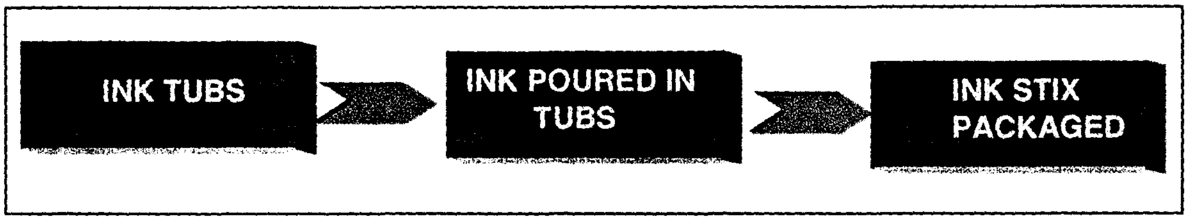

Figure 1b. Basic process flow diagram-Continuous Process

3.C. Brainstorming –Fishbone

We met the very next day, February 1 1997. During the meeting, we first analyzed the entire manufacturing process. The question and answer period with key employees along with a combination of brainstorming and grouping similar attributes was used to produce a list of most probable causes for ink stix height deviations from desired specifications.

The six "M" categories were identified as:

1. Manufacturing Environment
2. Materials
3. Machines
4. Methods
5. Measurement
6. Manpower

This is schematically represented using a "fishbone" diagram (Please see Figure 2. Fishbone Diagram).

3.C. Work Load --Gannt Chart

After obtaining a clear and through understanding of the ink-stix manufacturing process, as shown from Figure 2, we develop a "plan of attack, POA". Each person was assigned a specific task based on our POA, and was responsible to complete the task within a defined time line (Please see Appendix 1. Gannt Chart,).

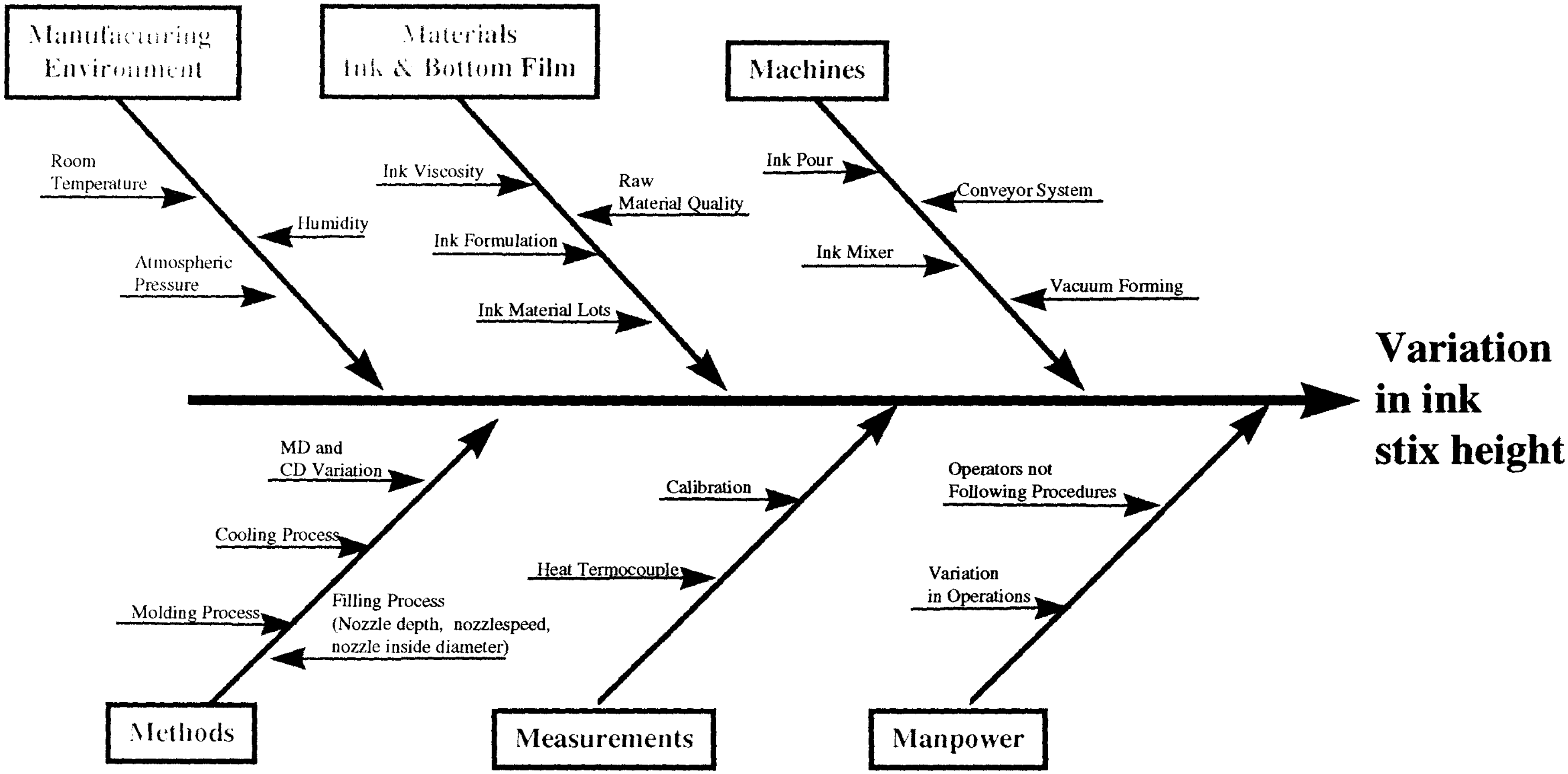

Figure 2. 6M Fishbone Diagram of the Ink Stix Height Variation Problem

SECTION 4.

EXPERIMENTAL / DATA GATHERING

In order to asses the status of ink stix manufacturing, we first needed to know whether we are in control.

4.A. Is the process statistically in control?

One of the most important questions was to determine whether the ink stix manufacturing process was statistically in control.

Potential key process variables that might play an important role in ink stix height variation were identified and listed by an experienced process engineer. Using the process engineer's list and the fishbone diagram, we outlined the key factors to be investigated as follows:

a. Ink stix raw material properties
b. Finished product nozzle to nozzle variation
c. Finished product process variation

4.B. Data Gathering Template

Using our knowledge of the process, a data gathering template was created such that all the information needed be collected in a statistically sound manner. This template included two sections:

Section 1. Ink Stix Raw Material Properties

This section lists the critical attributes of the ink stix raw material that are:

- Ink hopper temperature
- Head temperature
- Product temperature
- Cover temperature
- Heated hose temperature
- Volume setting
- Chiller temperature
- Vacuum setting
- Vacuum hold
- Nozzle depth
- Room temperature
- Lower preheat
- Upper preheat

Section 2. Finished Product, Ink Stix, Properties

This section presents the height and mass attributes of the finished product, ink stix. In order to evaluate the nozzle to nozzle and the process variation, we needed to identify the nozzle that created the ink stix.

The continuous part of the ink stix manufacturing process involving 12 nozzles were numbered as shown in Figure 3.

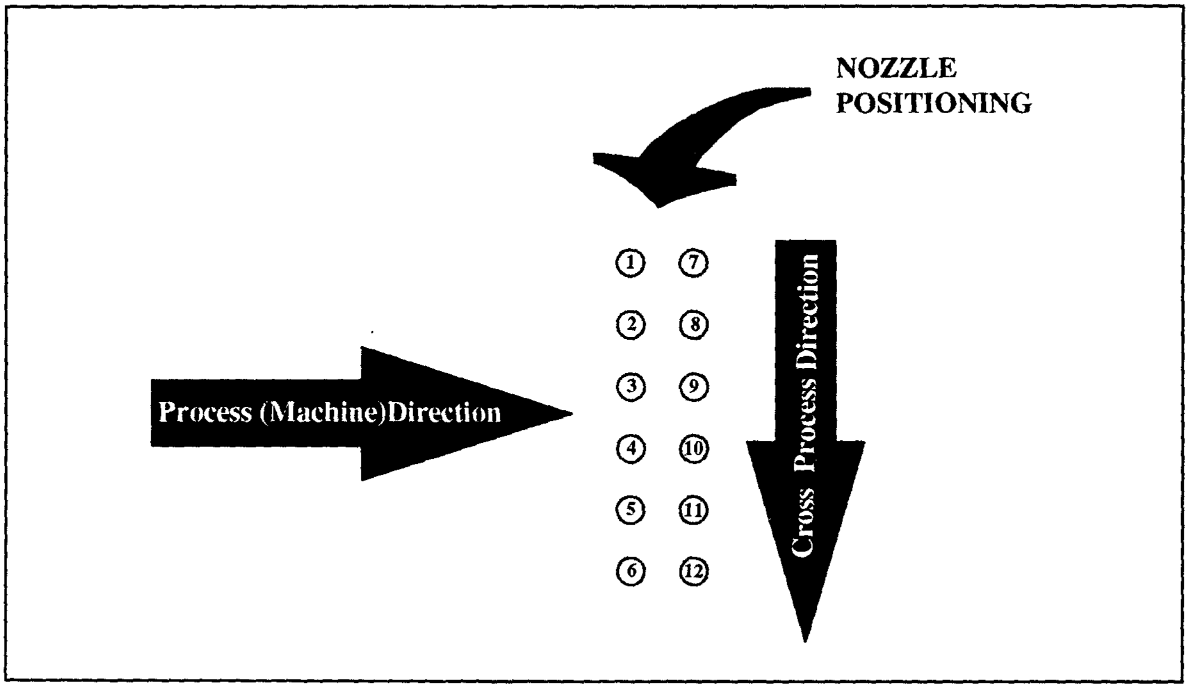

Figure 3. Cross Process Direction and Process Direction Illustrating Nozzle Positioning

At each nozzle position, 3 ink stix were collected for each sample set and tested for the followings:

- First stix initial height
- First stix final height
- Ink stix height / each nozzle
- Ink stix mass / each nozzle

Based on these, data gathering template was created as shown in Figure 4.

batch #	sample#	viscosity	time	shift
RK 1138				

ink hopper
hopper temp
head temp
product temp
cover temp
heated hose temp
volume setting
chiller temp
humidity
atm. press.
temp room

tiromat
lower preheat
upper preheat
vacuum setting
vacuum hold
nozzie depth

first stick initial height
first stick final height

nozzle#	height 1	height 2	height 3	mass(g)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				

Figure 4. Data Gathering Template

4.C. Sample Size

In order to investigate nozzle to nozzle variation, we needed to sample from each nozzle position, a total of 12 nozzles. When investigating the process variation, we were required to sample more than one batch, and several times per batch.

Other considerations when selecting a sample size were:

a. The sample size had to be large enough to be statistically sound
b. The sample size had to be small enough to be tested in a short time
c. The sample size had to be small enough so that economically reasonable

Based on the above mentioned criteria, we decided to collect at least 6 sample sets (each set consists of 12 nozzle positions) per batch, and test at least 3 batches.

4. D. Data Collection

Once the data gathering template was created and the sample size determined, Dawn Greenwell started collecting the data as outlined previously on February 3, 1997.

She measured 3 bathes of ink stix produced, over 30 sample sets at 12 nozzle positions (3 ink stix / each nozzle position/sample set/batch), yielding a total of 3240 ink stix height measurements. She measured the mass of the same ink stix once for a total of 1080 measurements. The total time spent on the measurement was approximately 8 day. However, please be aware of the fact that she is a full time employee with other responsibilities, and performed these tests on a overtime basis. Therefore, it took significantly longer than 8 days, as expected (approximately 1.0 month).

The data was recorded on clean room paper during the ink stix production process. It was later transferred to computer data file manually by IQIT team members. This approximately took 6 hours work.

SECTION 5.

RESULTS AND DISCUSSION

This part is the heart of our study. We have collected tremendous amount of data and it now time to analyze them and bring out our learnings to the surface. We divided this section into two:

A. Control Charts
B. ANOM Analysis

Detailed discussion on the methods used and the results revealed from the methods used is as follows.

5.A. Control Charts

Khalid has left the country and we have no way of contacting him. Therefore, we do not have access to his section-control charts.

We prefer not to include his incomplete analysis.

5.B. Analysis of Means, ANOM - CDVS

Before discussing the results obtained and our conclusions, we would like to define what is CDVS, cross direction variation study, first. Then, we will take you step-by-step through the CDVS process explaining at every step what needs to be done and what was done and the results of that step.

Definition of CDVS - Purpose And Uses Of CDVS

The primary purpose of this cross direction variation study (CDVS) is to provide data and statistical analysis to support a sound, low risk judgment as to whether a CD profile is flat or not:

Hypothesis: Is CD profile "flat"?

In other words, a CDVS provides a means to judge whether or not the sub-streams in a process are producing product with the same average level of properties.

A judgment of "non-flat" should be used to initiate process improvement work aimed at flattening the CD profile. This is because product from all CD positions (sub-streams), as well as from distinct processing lines, should be characterized by the same set of statistical distributions on product measurements.

The Steps Taken

Here are the steps taken when investigating the process variation using CDVS program:

1. Clarify objective

Since the control charting of the ink stix height is not a common practice at Tektronix, control charting of the height and the weight attributes of the ink stix was performed first. Control charts showed that ink stix manufacturing process is out of control.

CDVS study might reveal valuable information regarding the possible causes for being statistically not in control.

2. Develop Sampling Plan and Sample Size

There has been no analyses done regarding the process or the flow variation. Therefore, the first step in the sampling plan was to determine what to measure and then how often to measure. We have decided to number the nozzles in the process as shown in Figure 3.

Please refer to Section 4 for further information the development of sampling plan and selection of sample size.

3. Collect Sample and Make measurements

Please refer to Section 4 for further information.

4. Analyze Measurement Data

The data was analyzed plotting auxiliary s-chart and the main ANOM (Analysis of means) chart of each cross direction position (nozzle number) averages.

The results are presented for both height and weight attributes of the ink stix and are given in Appendix 1. CDVS ANOM Analysis.

5. Interpretation of the Analysis - Statement of the Process Condition

The CDVS analyses was performed separately for the first 6 nozzles (nozzle 1 through 6) and the last six nozzles (nozzle 7 through 12) to reveal if there is a pairing problem.

A. Ink Stix Height Attribute

Ink height ANOM analysis showed that ink height variation is out of control (non-flat).

- Measured ink height was nozzle position dependent.
- Positions 7 through 12 showed the same trend as positions 1 through 6.
- Batch to batch variation was much lower than nozzle to nozzle variation. ✓

B. Ink Stix Weight Attribute

Ink weight ANOM figures showed that ink weight variation is also out of control (non-flat).

- Measured ink weight was nozzle position dependent.
- Positions 7 through 12 showed the same trend as positions 1 through 6.
- Nozzle to nozzle variation was much higher than batch to batch variation. ✓

6. Interpretation of the Analysis - Conclusion

- Ink stix manufacturing process has cross process variation, CPV, problems. The CPV profile is not flat.
- There is a pairing between the nozzles. Nozzle no 1 and 7; 2 and 8; 3 and 8; 4 and 10; 5 and 11; and 6 and 12 show similar trends in terms of both height and weight attributes.
- In general, ink stix produced by outer nozzles have higher height than that of inner nozzles.
- Batch to batch variation seems to be negligible compared to nozzle to nozzle variation.

7. Recommendations / Actions to Take

Based on the CDV analysis results, we recommend that the following action should be taken to flatten the CDV profile:The fact that outer nozzles produce ink stix that are higher in height that that of produced by inner nozzles might be because of the non-uniformity in cooling down process.

- Based on this, we would like to suggest to isolate the outer nozzles. Apply the same process in sampling and data gathering, analyze the data in a similar manner and compare the results.

After examining the maintenance log book, it was noted that the ink delivery machine had not had its "O"-rings changed in over a year. The cost of changing the "O"-rings was twenty-five dollars and one hour of labor. It was suspected that faulty "O"-rings could allow ink to bypass the piston causing inconsistent ink delivery. Based on this observations, we suggest to:

- Replace the silicon "O" rings with viton "O" rings to reduce the leakage.

SECTION 6.

COUNTERMEASURES

Based on the recommendations as outlined in Section 5.B.7, countermeasures were designed and implemented to the manufacturing process at Tektronix.

Using the same sampling and data gathering approach, two more batches of ink stix were tested. After the data was transferred into excel worksheet, the individual data points were control charted. In addition, ANOM analysis was also performed to see if the countermeasures has improved the CDV profile (Please see Appendix 3 for ANOM figures and control charts).

SECTION 7.

CONCLUSIONS

After insulating the outside of the ink delivery machine with a silicon foam insulation in the quality control laboratory, the operators immediately reported an improvement in the number of reject sticks.

Our analyses results also showed that:

- After adding insulation, the process control charts show fewer number of signals (any points that are outside the limits of the control chart).
- Adding "O"-rings to the existing insulation also showed some improvement.

SECTION 8.

RECOMMENDATIONS

- Depending on the results obtained from counter-measures, we believe that there is a need to insulate the entire nozzle system with a fuller "jacket" of insulation.

When we started to work on this project, there were two materials (finished product themselves and the plastic film vacuum molded ink stix cups) that needed to be investigated. Due to the time consuming nature of the analyses methods applied and the limited time allowed to finish the project, we had to choose one of the materials in our investigation. As you can imagine, we have investigated "ink stix" material.

From our investigation, we found out that there are some process problems caused by the filling system and suggested couple of improvements (isolation, "O"-rings). However, we would like to take your attention to the fact that there is no correlation between the height and the weight of ink stix tested. If the vacuum molding system was in statistical control (which has not been proved yet), one would **expect to see a correlation between the height and the weight of the ink stix**.

Based on this observation, we strongly suggest to investigate the effect of the other material, plastic film vacuum mold ink stix cups, for your process control. This will allow you to pinpoint where the problem is coming from: Ink stix themselves? Or Ink stix cups?

In terms of how to investigate the impact of ink stix vacuum cups, we would like to suggest you follow a similar approach:

- Instead of testing the finished product ink stix height and mass, the height and the volume (not mass) measurements should be taken on the individual film molds that hold the ink stix.

SECTION 9.

CURRENT ACTIONS -

WHAT'S HAS BEEN CHANGED AT TEKTRONIX?

After reliazing the true variance of the process demonstrated via our team project, Tektronix is now paying attention to the statistical process control and giving it a much higher priority.

- Our project results encouraged the management to take a closer look at the manufacturing process and how they can be improved to meet the new platforms created by the new products. In order to do this, a temporary operator will be hired to weigh and measure sticks for a period of three months in order to gather the data needed to identify the cause(s) of the ink stick height variation. Tektronix reliazed that with the constant struggle to provide better print quality comes with the long battle to create printers with tighter specifications.
- A quality program is in the process of being implemented. This quality program is designed to ensure that ink stix were meeting specifications before leaving the plant.
- The lead engineer for the ink stix manufacturing line developed a traveler, process data sheet, that would have the operator to sample each run ten times instead of just once, old way.
- All data will now be recorded on the data sheet along with any changes made to the process. In the past, the operator would sample the line and change the process and only write down the final ink stick height. None of the process changes were annotated. **This in itself was a great improvement.**