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DETERMINE ENERGY REQUIRED TO FORM HEALTHY DRIVE BUBBLE

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Determine Energy Required to form Healthy drive Bubble

Abstract: A new method of determining the minimum energy to form a drive bubble is presented. This new method uses an on-die drive bubble detect circuit to infer when the ink chamber is dry by measuring the charge on the sensor plate in the chamber. The pen can be brought up to temperature, and then fire a nozzle with various energy pulses to detect at what energy a drive bubble is formed. A plot of the firing energy vs drive bubble detect signal is then used to infer the minimum energy to eject a drop.

Typical in Integrated Circuit manufacturing the variation in circuit performance can lead to die that have a spread of circuit performance and a method is needed to determine the minimum energy required to eject drops. Most print systems can determine this energy by spitting multiple drops from many nozzles and monitor the temperature of the pen. This is typically done by firing with more energy than required and stepping the energy down and monitoring the temperature response. With too much energy, the ink is ejected and the excess energy results in more heat in the die. As the energy delivered is decreased, the die temperature response begins to cool until the energy in equals the energy out. If one further decreases the pulse width (energy) the ink is no longer able to eject, but the pulse will heat up the die once again. With this Thermal Turn on Energy (TTOE) method, ink is wasted and the time to collect this information is several seconds.

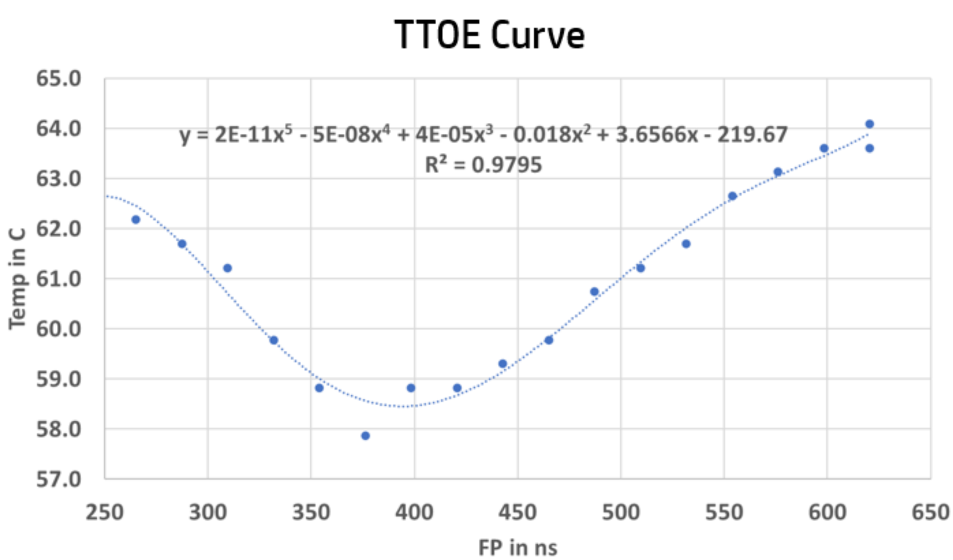

Figure 1: Thermal turn on Energy Curve. The minimum energy for the Fire Pulse to eject is close to 400 nano seconds.

With Drive Bubble Detect (DBD), the on-die sensor can monitor the health of the drive bubble as a function of the fire pulse energy. Since the DBD sensor is in each firing chamber, one can select one nozzle to determine the energy required to eject ink. This reduces the amount of drops fired significantly from that of TTOE in which many nozzles must fire to get a thermal response. The die can also warm to the print setpoint temperature with Drive Bubble Detect Tun On Energy (DTOE) since the on-die temperature system is not used as a response. The DTOE method thus has several benefits (less time, less drops, constant temperature, better accuracy). The DTOE curves will vary with ink and die architecture, so a robust method to calculate the point for minimum energy is required.

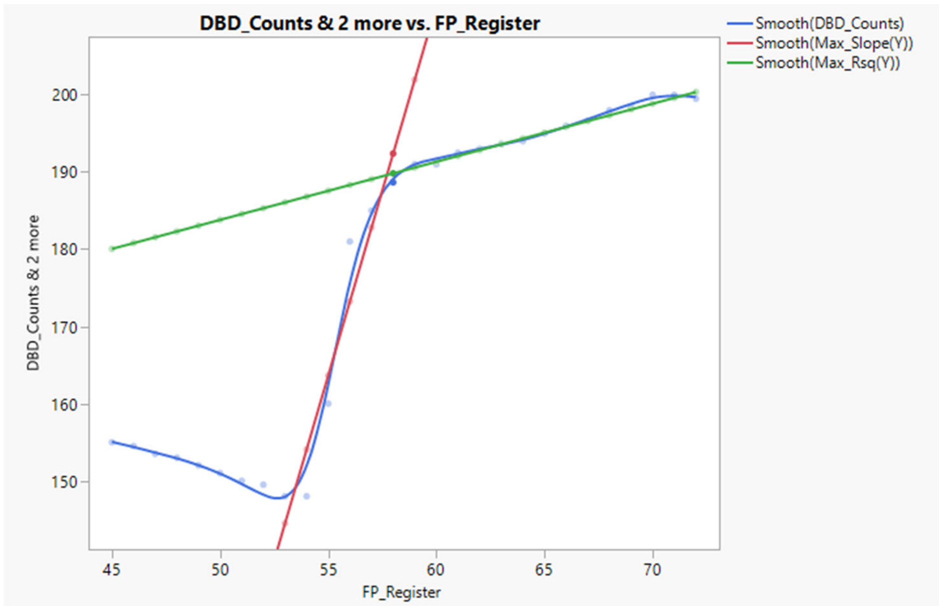

Figure 2: DTOE Curve (blue). The DBD response is plotted vs FP Register setting (Energy). The red line is based off an algorithm to find max slope of 6 data points. The green line is based off an algorithm to find 6 data points higher in energy than the max slope with a high R-squared value.

After collecting the DBD counts vs firepulse an algorithm is used to find the point to call the minimum firing energy. The algorithm finds the highest running slope, then finds a line with a high fit value (R-squared) that is towards the high energy side. The intersection of these two lines is used to find the closet point or minimum energy to have a healthy drive bubble. The algorithm uses a running slope method using 6 data points, but one could use more or less points to calculate a slope. Matrix algebra is used to calculate the slope and intercept for the data points collected in a table format. Using JMP statistical software the equations look like

- Equation 1 : Finding Slope
  - If(Row() > 5, // Be sure 6th data point in data set is used
    - x = J(6, 1, 1) || :FP_Register[Index(Row() - 5, Row())]`;
      - // Setup X matrix [1 72 (highest row), 1 71, … 1 66], for the 6 data points
    - y = :DBD_Counts[Index(Row() - 5, Row())]`;

    - // Setup y Matrix [Y1, Y2, Y3, Y4, Y5, Y6] for the six data points
  - (Inv(x` * x ) * x` * y)[2];)
    - // Calculate or Solve for the 2nd row of output matrix (this is slope)

- Equation 2 : Find Intercept
  - If(Row() > 5, // Be sure 6th data point in data set is used
    - x = J(6, 1, 1) || :FP_Register[Index(Row() - 5, Row())]`; // Setup X matrix [1 72 (highest row), 1 71, … 1 66]
    - y = :DBD_Counts[Index(Row() - 5, Row())]`; // Setup y Matrix [Y1, Y2, Y3…Y6]
    - (Inv(x` * x ) * x` * y)[2];)
      - // Calculate or Solve for the 1st row of output matrix (This is the Intercept)
- Equation 3 : Calculate R-Squared
  - If(Row() > 5,
    - X = J(6, 1) || :FP_Register[Index(Row() - 5, Row())]`; // Same as above
    - Y = :DBD_Counts[Index(Row() - 5, Row())]`; // Same as above
    - y_bar = Mean(:DBD_Counts[Index(Row() - 5, Row())]`); // Determine mean for the 6 points
    - B = Inv(x` * x ) * x` * y; // Solve for Slope and intercept
    - R2 = (B` * X` * Y - 6 * y_bar ^ 2) / (Y` * Y - 6 * y_bar ^ 2);)
      - // Solve for R-squared (Fit of line)

Once the max slope is found, then find a fitted line of 6 data points that is higher in energy and has a best fit using equation 3. Once this data point is found the corresponding Slope (equation 1) and intercept (equation 2) is used to calculate the line with the maximum R-squared. The point of intersection of these two lines is then the DTOE value

- E.g., Y1=M1 X + B1 (Highest Slope) & Y2=M2 X + B2 (High R-squared fit at higher Energy)
  - Equation 4, DTOE = (B2 – B1) / (M1 – M2)

Using these equations, a representative table is shown in Table 1.

Table 1 : Showing the slope, intercept, R-sq and DTOE counts.

Row	FP_Time	FP_Register	DBD_Counts	6pt_Lagfit_slope	6pt_Lagfit_Intercept	R-sq	Max_Slope_Row	Max_R-sq_Row	FP_DTOE_Counts	Max_Slope(Y)	Max_Rsq(Y)
1	0.7333333333	72	164	•	•	•	19	15	58	252.4984127	132.79365079
2	0.7111111111	71	162.5	•	•	•	19	15	58	242.46984127	131.55555556
3	0.6888888889	70	159	•	•	•	19	15	58	232.44126984	130.31746032
4	0.6666666667	69	156	•	•	•	19	15	58	222.41269841	129.07936508
5	0.6444444444	68	150.5	•	•	•	19	15	58	212.38412698	127.84126984
6	0.6222222222	67	137	4.9714285714	-190.6809524	0.8679216436	19	15	58	202.35555556	126.6031746
7	0.6	66	131	6.5428571429	-298.852381	0.9354719786	19	15	58	192.32698413	125.36507937
8	0.5777777778	65	125	7.3857142857	-355.452381	0.968935746	19	15	58	182.2984127	124.12698413
9	0.5555555556	64	121	7.3571428571	-352.5	0.9676742616	19	15	58	172.26984127	122.88888889
10	0.5333333333	63	121	5.7571428571	-246.1761905	0.8893356819	19	15	58	162.24126984	121.65079365
11	0.5111111111	62	120	3.4	-93.46666667	0.8688618468	19	15	58	152.21269841	120.41269841
12	0.4888888889	61	120	2	-4	0.744680851	19	15	58	142.18412698	119.17460317
13	0.4666666667	60	119	0.9714285714	60.285714286	0.7506493512	19	15	58	132.15555556	117.93650794
14	0.4444444444	59	117	0.7428571429	73.980952381	0.8521008403	19	15	58	122.12698413	116.6984127
15	0.4222222222	58	114.33333333	1.2380952381	43.650793651	0.8768592184	19	15	58	112.0984127	115.46031746
16	0.4	57	108	2.2571428571	-17.91111111	0.8265211527	19	15	58	102.06984127	114.22222222
17	0.3777777778	56	94	4.7333333333	-164.8444444	0.8110400306	19	15	58	92.041269841	112.98412698
18	0.3555555556	55	77	8.1523809524	-363.8730159	0.8672937314	19	15	58	82.012698413	111.74603175
19	0.3333333333	54	72	10.028571429	-469.5587302	0.9485769608	19	15	58	71.984126984	110.50793651
20	0.3111111111	53	72	9.619047619	-444.3015873	0.9263586776	19	15	58	61.955555556	109.26984127
21	0.2888888889	52	72	7.1714285714	-308.3428571	0.7870697733	19	15	58	51.926984127	108.03174603
22	0.2666666667	51	72	3.5714285714	-114.5714286	0.5760368664	19	15	58	41.898412698	106.79365079
23	0.2444444444	50	72	0.7142857143	35.333333333	0.4285714284	19	15	58	31.86984127	105.55555556
24	0.2222222222	49	72.333333333	-0.047619048	74.507936508	0.4285713978	19	15	58	21.841269841	104.31746032
25	0.2	48	73	-0.171428571	80.879365079	0.631168829	19	15	58	11.812698413	103.07936508
26	0.1777777778	47	73	-0.238095238	84.174603175	0.8241758232	19	15	58	1.7841269841	101.84126984
27	0.1555555556	46	73	-0.247619048	84.565079365	0.8521008411	19	15	58	-8.244444444	100.6031746
28	0.1333333333	45	74	-0.342857143	89.174603175	0.8678571439	19	15	58	-18.27301587	99.365079365

In summary, using DBD data to determine the minimum firing energy has been shown with the example above. This methodology can be used within the print system as long as the pen has DBD sensors. Using the DTOE method will decrease the amount of ink spit, and a minimum energy setting can be found in much less time.

Disclosed by Vincent C Korthuis, HP Inc.