A STATISTICAL ANALYSIS OF THE SHOT PEENING INTENSITY MEASUREMENT

Richard C. Wieland
Chief Operating Officer
Advanced Material Process Corporation
Wayne, Michigan 48184 U.S.A.

Abstract

This paper includes a statistical analysis of the variability involved in determining the Almen saturation required for processing a given work piece, and compares this variability with several manufacturing standards currently being used to determine Almen saturation. The data indicates that variability in the Almen measurement system is large enough to suggest that simply conforming to established manufacturing standards is unlikely to produce an acceptable result. An alternative methodology is proposed based on statistical measurements that can predict the number of non-conforming parts produced. The alternative methodology also provides a possible method for predetermining the statistical capability of a given shot peening system.

Key Words

intensity, work piece saturation, Almen saturation, statistical saturation, intensity curves, cycle time

Introduction

The basic concept of Almen saturation is to determine the first point in time at which a workpiece exposed to a blast stream of uniform process variable characteristics is impinged all over the desired area in order that its surface be entirely and uniformly cold worked.

The precursor of our present manufacturing standards used to determine Almen saturation required for processing a given work piece can be traced back to J. O. Almen's patent (1). The objective of this patent was to provide a means of measurement and a methodology for determining the effectiveness of the shot peening process. Since this patent was issued improvements in the peening process have been made but apparently little if any change has occurred in the basic methodology for determining the intensity to which a given work piece must be processed to obtain a desired result.

Three of today's more commonly used specifications for the determination of intensity are SAE J442/J443 (2), MIL-S-13165C (3), and AMS 2432 (4). They are summarized in Table I. Although these specifications are not identical they are similar; each seeks to: a) nominally define the "knee" of the curve, b) determine the saturation point in cycle time generally defined as the cycle time where doubling the cycle time will achieve an increase in Arc height of not greater than 10%, and c) use a number of Almen strips, with no specification requiring more than a total of four strips.

Within our facility we experience variation in the determination of the cycle time for processing a part when using any of the above methodologies for determining Almen saturation. To determine the root cause for the variation the following experimental procedure was performed.

Experimental Procedure

An air blast machine (with four nozzles only one used during test) utilized in daily high volume production was selected for the test work. The nominal settings for seven shot peen process variables and their maximum acceptable tolerances used for this study are summarized in Table II. These setting were chosen in conjunction with pre production test work performed at our processing facility.

The air blast nozzle internal diameter was checked using a standard go-no go gauge before and after testing and showed no measurable wear, air pressure measured after the regulator but before the magnetic valve was calibrated and regulated using a nanometer accurate to 0.005 pounds per square inch, Vulkan (Fromme) cut wire SCCW 20 was selected, shot flow rates were calibrated using real time catch tests and monitored with an Electronics Incorporated Shot Flow Controller Model 362A, the nozzle to test strip center location was determined by tracer dye removal and was checked before and after testing, the shot impact angle on the test strips was calibrated and checked before and after testing using a protractor/level, test strip motion initiated at the start of each test at the same location and was monitored using a turntable calibrated by stop watch at the beginning and end of each day.

The Almen strips used for this test were chosen from a common lot obtained from Associated Spring and individually inspected for flatness using an Almen Gage #2. Of 1,053 strips examined 487 strips with a tolerance of less than or equal to 0.0001 inch were selected for use. Figure I shows the flatness distribution of the strips inspected.

All strip mountings and removals were done using a systematic method with readings taken by the same operator using a Almen Gage #2. The repeatability of these readings were crossed referenced to an Electronics Incorporated Almen Gage #3 and found to be the same.

Results

Walpole and Myers (5) served as the reference for experimental and statistical methods used for initially determining the number of sample readings required and for analysis of the data and interpretation of the results. It was determined that a minimum of 10 data points for each cycle time were needed for calculation of the standard deviations but that approximately 30 data points were needed for accurate approximation of the mean arc heights for each cycle time as defined by the Central Limit Theorem.

A total of 388 Almen strips were processed at different cycle times in order to identify the shape and repeatability of the intensity curve used in this preproduction process setup. Individual arc height readings are listed in Table III, summarized in Table IV, and graphically represented in Figure II.

The sample standard deviations exhibited surprisingly similar results across the entire range of cycle times from a low of +/- .00013" to a high of +/- .00021" (Table III). It was originally thought that for low saturation levels the resulting arc heights would show considerably larger standard deviations. This was not the case for these test conditions.

Normality of the data distributions for all cycle times was checked with all sample cycle time populations. They were found to be normally distributed. The test of normality is important because it is a key assumption for calculating the standard deviation of the paired observations. In addition if normality of the distributions exist, when the standard deviation of the paired observations is calculated the error of the means is included.

Discussion

The mean percent difference decreased from 44.67% for the 40/20 seconds pairing to 5.6% for the 200/100 seconds pairing (Table IV). If it is assumed that the sample standard deviation of Almen arc height values was zero, it can easily be extrapolated from Table IV that the cycle time would be 67 seconds. This has already been shown not to be the case (Table III).

Standard deviations of the percent differences referred in Walpole as the standard deviation of the paired observations, ranged from +/- 3.79 to +/- 1.44 (Table IV). Utilizing the data in Table IV it can be shown that to be 3 sigma capable to less than 10% (one of the more generally accepted quality levels) requires a time of 100 seconds (Figure III). This is calculated by taking the standard deviation of the mean % difference 1.77, multiplying by 2.78 (normally one would use 3.00 but the 10% value is a lower specification limit whereby 99.73% of all data would be from -2.78 standard deviations to infinity) to give 4.92 which is then added to the mean % difference of 5.60 to obtain 10.52%. This represents .27% non-conformance (2,700 parts out of 1,000,000).

If one were to use the methodology specified in AMS 2432 or MIL-S-13165C it would be possible to establish a 60 second Almen saturation point, a full 7 seconds below the cycle time for a peening system assumed to have zero sample standard deviation of Almen arc height values. This would result in a 81.33% non-conformance of Almen saturation (813,300 parts out of 1,000,000). The reason for this is that AMS 2432 and MIL-S-13165C only require 4 Almen strips to establish saturation. With such a small number of strips Almen saturation becomes 'luck of the draw' rather than a statistically determined point.

An even worse case occurs if one were to use the methodology specified by SAE J442/J443 in that it would be possible to establish a 40 second Almen saturation point, a full 27 seconds below the cycle time for a peening system assumed to have zero sample standard deviation of Almen height values. This would result in a 93.94% non-conformance of Almen saturation (939,400 parts out of 1,000,000). The reason for a higher nonconformance by SAE J442/443 over AMS 2432 and MIL-S-13165C is SAE J442/443 only requires 2 Almen strips to establish saturation.

The variation in the outcome of saturation curves when using either AMS, MIL, or SAE specifications referred to in the Introduction can now easily be explained. These specifications assume a shot peen process saturation curve to be a line on an Almen arc height versus exposure time chart, that has zero as its sample standard deviation of Almen arc height values. In reality, an Almen Saturation curve for any given shot peen process will have a range of arc heights for each exposure time (Figure II). The total range in arc height at any given exposure time will be directly related to the shot peen process and process measurement system variability experienced during the shot peening of the Almen strips and measurement of the same (6).

If the standard deviation of the Almen arc height values increased to approximately +/- .00036 this peening system would become incapable of 3 sigma processing, even if the product was run for an infinite length of time.

Conclusions

With the variation in the Almen strip readings as great as they are it is apparent that the determination of the shot peening intensity measurement is a more complicated task then that imagined by J. O. Almen or defined by SAE, MIL, and AMS specifications.

A statistical shot peening intensity measurement is possible with the tolerances in the processing parameters evaluated statistically over a large number of

Almen Strips to determine the true minimum exposure time to get 100% Almen saturation for a 3 sigma (99.73%) statistical assurance.

If tolerances for processing are loosely defined, controlled and monitored, the additional time needed to compensate for process variability could be greater than infinity using the generally accepted 10% for determining the point of minimum Almen strip exposure time, if one assumes a 3 sigma reliability.

As tolerances for the shot peening process are more tightly defined, controlled and monitored (7), the additional time needed to compensate for process variability can become almost zero. When this happens, shot peening is not only a statically capable process, but can be a much more cost effective process than it already is (8) in that less time means lower shot consumption, less machine wear, lower energy bills, higher machine utilization along with increased labor productivity, and on and on.

A process with increased statically capability offers the possibility of a more cost effective process with either higher quality at the same cost, the same quality at a lower cost, or any combination in between. The end result is flexibility to provide the quality (through statistical measures), price (through process optimization), delivery (through greater machine utilization), and service (by providing a method of understanding the process) that the industrial environment of today can demand.

References

(1) Almen patent 2,350,440

(2) SAE J442, "Test Strip, Holder And Gage For Shot Peening", August 1979; SAE J443, "Procedures For Using Shot Peening Test Strip", January 1984; SAE, 400 Commonwealth Drive, Warrendale, Pa 15096-0001.

(3) MIL-S-13165C, "Shot Peening Of Metal Parts", 7-June-1989, Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, Pa 19120-5099.

(4) AMS 2432, "Shot Peening, Computer Monitored", 1-October 1990, SAE, 400 Commonwealth Drive, Warrendale, Pa 15096-0001.

(5) Walpole, R. E.; Myers, R. H., "Probability and Statistics for Engineers and Scientists", Fourth Edition.

(6) Simpson, R.S., and others unknown, "Why is it Broken".

(7) Vincek, Michael R., Joyner, James E., "Computer Integrated Manufacturing for the Shot Peening Industry Implemented in an Empowered Environment", ICSP-5, 1993.

(8) Vahration, Adam J.; Garibay, Robert P., "Application Of Statistically Capable Shot Peening To Automotive Component Design", ICSP-5.

TABLE I: REQUIREMENTS FOR ESTABLISHING AN ALMEN SATURATION CURVE

	NUMBER OF ALMEN STRIPS REQUIRED TO ESTABLISH SATURATION	PURPOSE OF SATURATION CURVE	DETERMINATION OF SATURATION POINT IN CYCLE TIME
SAE J442/J443	2	To nominally define the "knee" of the curve	When doubling cycle time will achieve not greater than a 10-20% increase in Arc height
MIL-S-13165C	4	To nominally define the "knee" of the curve	When doubling cycle time will achieve not greater than a 10% increase in Arc height
AMS 2432	4	To nominally define the "knee" of the curve	When doubling cycle time will achieve not greater than a 10% increase in Arc height

Table II. Nominal Settings For Seven Shot Peening Process Variables And Their Maximum Acceptable Tolerances Used For This Study

Process Variable	Nominal Setting	Acceptable Tolerance	Measured
Nozzle (Internal Diameter)	0.25	+0.000 -0.015	Inches
Air Pressure	40.00	+0.25 -0.25	Pounds Per Square Inch
Shot Size (Diameter)	0.0225	+0.0027 -0.0027	Inches
Shot Flow Rate (Per Nozzle)	5.00	+0.25 -0.25	Pounds Per Minute
Nozzle To Test Strip Distance (Center Location)	6.00	+0.125 -0.125	Inches
Shot Impact Angle (On Test Strip)	90.00	+3 -3	Degrees
Test STrip Motion	25.00	+0.50 -0.50	Revolutions Per Minute

FIGURE I: ALMEN STRIP FLATNESS DISTRIBUTION AS RECIEVED FROM A BATCH OF 1053 STRIPS

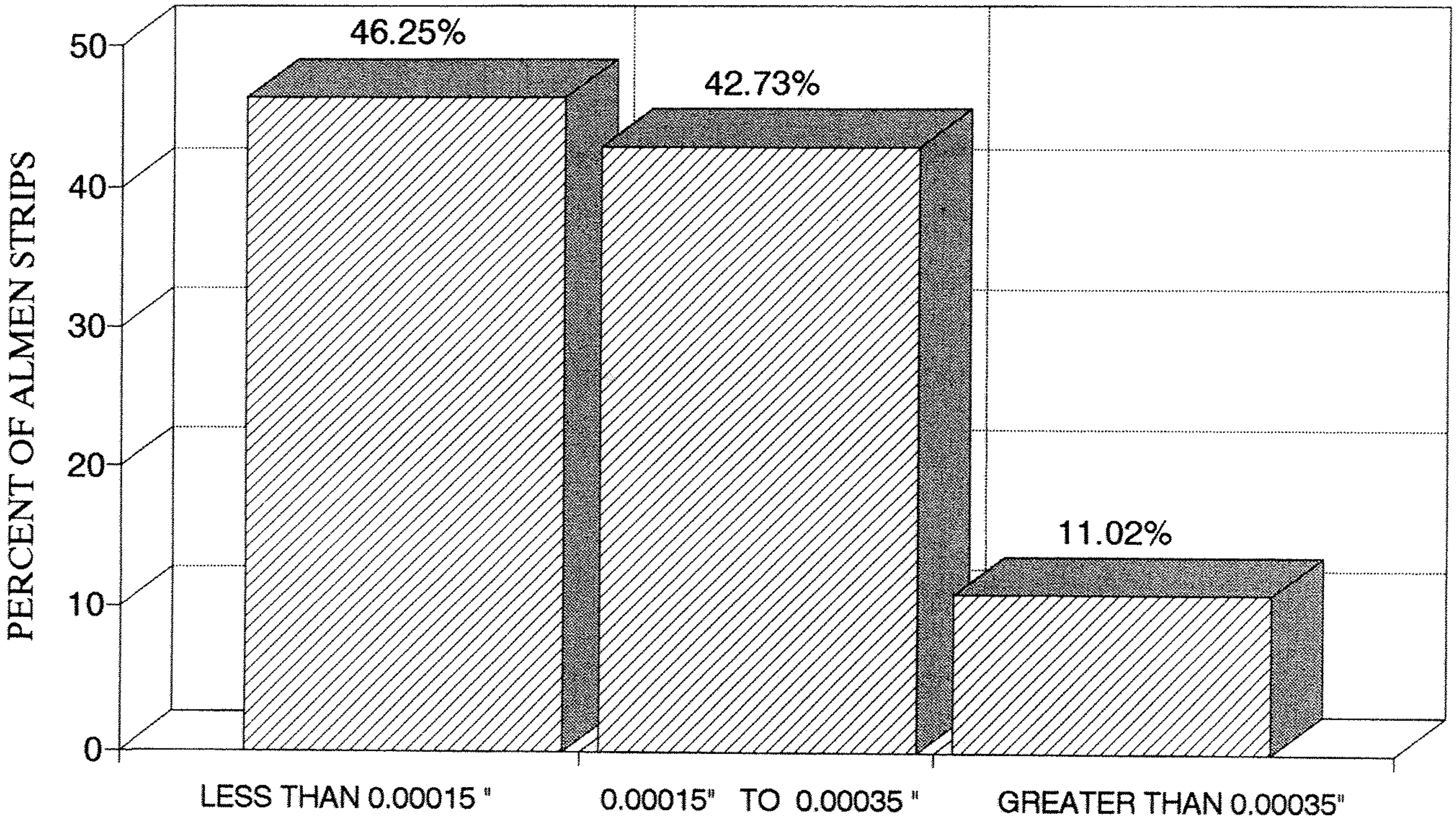

TABLE III: DATA AND ANALYSIS OF DATA FROM TEST PROCEDURE

SAMPLE ORDER	CYCLE TIME 20 SEC	40 SEC	50 SEC	60 SEC	70 SEC	80 SEC	90 SEC	100 SEC	110 SEC	120 SEC	130 SEC	140 SEC	160 SEC	180 SEC	200 SEC
1	0.0076	0.0109	0.0117	0.0125	0.0127	0.0130	0.0133	0.0135	0.0134	0.0140	0.0137	0.0139	0.0143	0.0141	0.0144
2	0.0073	0.0111	0.0119	0.0125	0.0129	0.0129	0.0134	0.0134	0.0138	0.0139	0.0135	0.0139	0.0140	0.0142	0.0145
3	0.0074	0.0105	0.0118	0.0122	0.0126	0.0130	0.0134	0.0134	0.0133	0.0136	0.0138	0.0139	0.0142	0.0147	0.0140
4	0.0078	0.0110	0.0119	0.0123	0.0126	0.0129	0.0131	0.0137	0.0138	0.0136	0.0139	0.0139	0.0144	0.0143	0.0141
5	0.0077	0.0110	0.0114	0.0123	0.0128	0.0129	0.0131	0.0135	0.0135	0.0139	0.0137	0.0140	0.0140	0.0142	0.0140
6	0.0074	0.0111	0.0117	0.0126	0.0126	0.0130	0.0131	0.0135	0.0135	0.0138	0.0138	0.0139	0.0139	0.0141	0.0141
7	0.0077	0.0109	0.0116	0.0124	0.0130	0.0129	0.0132	0.0135	0.0136	0.0138	0.0140	0.0139	0.0141	0.0145	0.0146
8	0.0077	0.0108	0.0117	0.0122	0.0127	0.0129	0.0132	0.0135	0.0135	0.0138	0.0139	0.0141	0.0139	0.0142	0.0142
9	0.0076	0.0107	0.0114	0.0126	0.0128	0.0132	0.0132	0.0132	0.0136	0.0135	0.0138	0.0138	0.0140	0.0144	0.0143
10	0.0074	0.0110	0.0116	0.0120	0.0130	0.0132	0.0133	0.0133	0.0136	0.0135	0.0138	0.0138	0.0142	0.0142	0.0142
11		0.0110	0.0117	0.0120	0.0128	0.0131	0.0135	0.0136	0.0139	0.0139	0.0138	0.0139	0.0139	0.0142	
12		0.0111	0.0116	0.0120	0.0126	0.0129	0.0134	0.0133	0.0136	0.0138	0.0136	0.0140	0.0141	0.0143	
13		0.0108	0.0118	0.0126	0.0128	0.0129	0.0135	0.0136	0.0136	0.0133	0.0140	0.0137	0.0140	0.0144	
14		0.0110	0.0119	0.0123	0.0129	0.0130	0.0128	0.0137	0.0136	0.0139	0.0140	0.0139	0.0141	0.0143	
15		0.0110	0.0116	0.0121	0.0128	0.0130	0.0131	0.0134	0.0133	0.0137	0.0138	0.0136	0.0140	0.0142	
16		0.0110	0.0118	0.0123	0.0128	0.0130	0.0133	0.0134	0.0139	0.0138	0.0140	0.0140	0.0142	0.0143	
17		0.0109	0.0117	0.0124	0.0127	0.0130	0.0132	0.0133	0.0138	0.0138	0.0140	0.0140	0.0141	0.0142	
18		0.0109	0.0118	0.0122	0.0126	0.0134	0.0131	0.0137	0.0139	0.0140	0.0136	0.0140	0.0139	0.0144	
19		0.0109	0.0116	0.0121	0.0127	0.0129	0.0136	0.0136	0.0135	0.0137	0.0138	0.0140	0.0140	0.0144	
20		0.0111	0.0113	0.0123	0.0129	0.0130	0.0136	0.0135	0.0136	0.0138	0.0138	0.0138	0.0139	0.0141	
21		0.0108	0.0117	0.0121	0.0128	0.0129	0.0136	0.0133	0.0136	0.0139	0.0139	0.0140			
22		0.0111	0.0114	0.0123	0.0125	0.0133	0.0135	0.0134	0.0138	0.0139	0.0142	0.0139			
23		0.0110	0.0117	0.0122	0.0128	0.0128	0.0134	0.0136	0.0133	0.0138	0.0135	0.0140			
24		0.0108	0.0117	0.0121	0.0129	0.0129	0.0134	0.0136	0.0135	0.0135	0.0139	0.0139			
25		0.0105	0.0118	0.0119	0.0129	0.0129	0.0133	0.0136	0.0136	0.0136	0.0140	0.0140			
26		0.0111	0.0118	0.0121	0.0129	0.0130	0.0134	0.0135	0.0135	0.0141	0.0140	0.0138			
27		0.0111	0.0116	0.0122	0.0127	0.0128	0.0133	0.0134	0.0136	0.0138	0.0141	0.0137			
28		0.0110	0.0119	0.0125	0.0128	0.0132	0.0130	0.0136	0.0135	0.0139	0.0139	0.0142			
29			0.0116	0.0122	0.0127	0.0129	0.0132	0.0135	0.0135	0.0138	0.0136	0.0138			
30			0.0116	0.0121	0.0129	0.0132	0.0134	0.0135	0.0137	0.0140	0.0138	0.0140			
SAMPLES	10	28	30	30	30	30	30	30	30	30	30	30	20	20	1
LOW=	0.0073	0.0105	0.0113	0.0119	0.0125	0.0128	0.0128	0.0132	0.0133	0.0133	0.0135	0.0136	0.0139	0.0141	0.014
HIGH=	0.0078	0.0111	0.0119	0.0126	0.0130	0.0134	0.0136	0.0137	0.0139	0.0141	0.0142	0.0142	0.0144	0.0147	0.014
MEAN=	0.00756	0.010932	0.011677	0.012253	0.012773	0.013	0.013297	0.013487	0.013597	0.01378	0.013837	0.01391	0.01406	0.014285	0.0142
STD DEV	0.000162	0.000163	0.000154	0.000189	0.000126	0.000144	0.000187	0.000128	0.000166	0.000178	0.000174	0.000122	0.000139	0.000146	0.00019
MEAN %=	44.61%	18.92%	15.50%	12.46%	8.90%	8.15%	7.43%	5.59%							

TABLE IV: SUMMARY OF DATA FROM TABLE 3 "COMPILATION OF ALMEN ARC HEIGHT READINGS FOR AN ALMEN SATURATION CURVE"

BLAST DURATION (SECONDS)	MEAN ARC HEIGHT (0.001")	STANDARD DEVIATION OF ALMEN ARC HEIGHT VALUES	NUMBER OF ALMEN STRIPS PROCESSED	MEAN % DIFFERENCE	STANDARD DEVIATION OF % DIFFERENCE
20	7.56	.17	10	44.67	3.79
40	10.93	.16	28	18.94	2.23
50	11.68	.16	30	15.52	1.89
60	12.25	.19	30	12.49	2.25
70	12.77	.13	30	8.91	1.44
80	13.00	.15	30	8.17	1.60
90	13.30	.19	30	7.45	1.88
100	13.49	.13	30	5.60	1.77
110	13.60	.17	30		
120	13.78	.18	30		
130	13.84	.18	30		
140	13.91	.12	30		
160	14.06	.14	20		
180	14.29	.15	20		
200	14.24	.21	10		

MEAN % DIFFERENCE: Percent increase in mean Almen arc height: Blast duration vs. 2x Blast duration

STANDARD DEVIATION OF % DIFFERENCE: The average deviation of percent increase in Almen arc height valu from the mean % difference.

FIGURE II: COMPILATION OF ALMEN ARC HEIGHT READINGS FOR AN ALMEN SATURATION CURVE

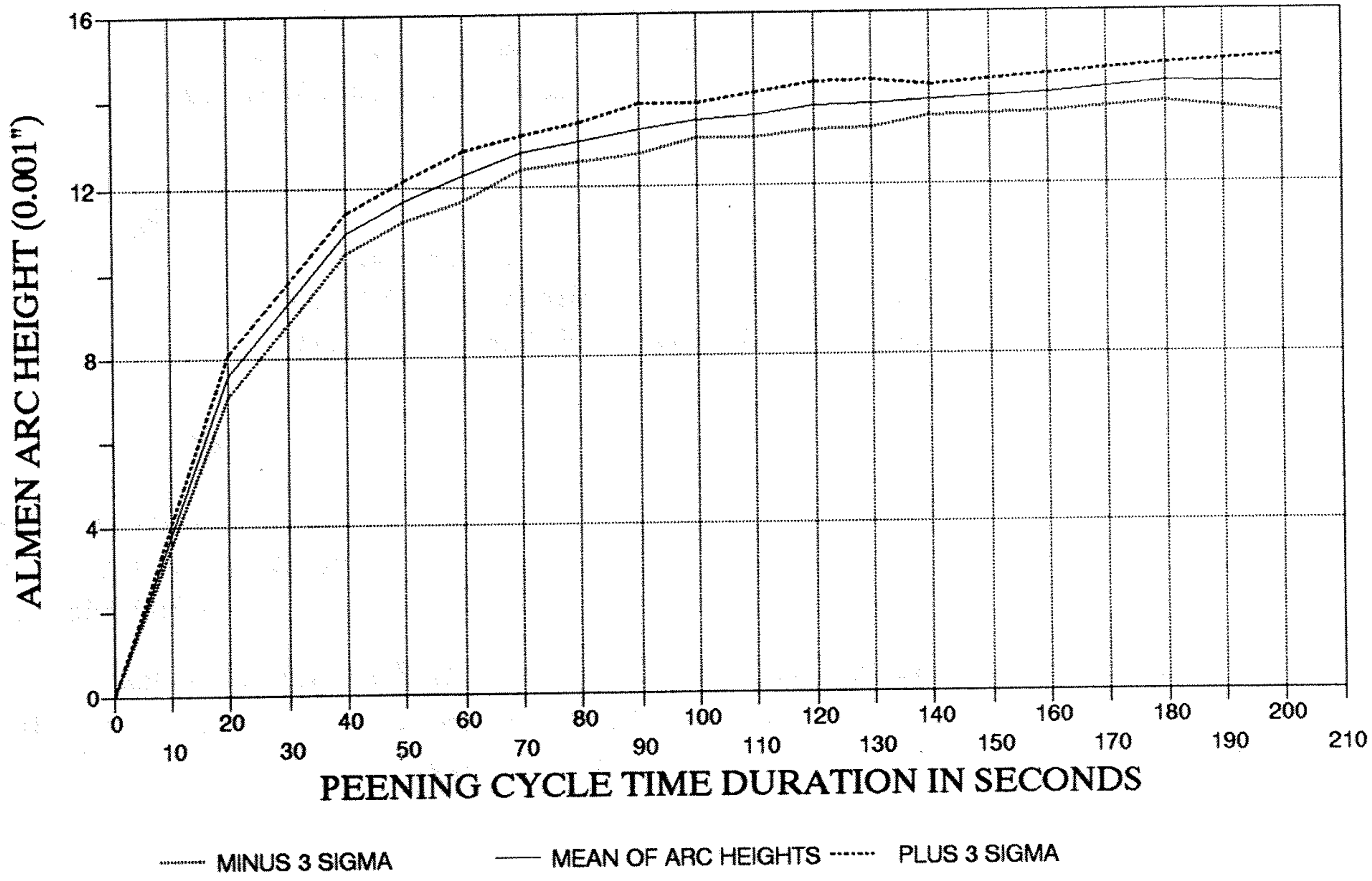

FIGURE III: WORST CASE PERCENT OF DATA NON-CONFORMING WITH THE REQUIREMENTS OF ALMEN SATURATION USING CURRENT SPECIFICATION GUIDELINES FOR DETERMINING ALMEN SATURATION