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PROCESS ACCEPTANCE AND ADJUSTMENT TECHNIQUES FOR SWISS AUTOMATIC SCREW MACHINE PARTS

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Division

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PROCESS ACCEPTANCE AND ADJUSTMENT TECHNIQUES FOR SWISS AUTOMATIC SCREW MACHINE PARTS

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Prepared by J. M. Robb, D/822, under EP 6984810

Tolerance requirements for small, cylindrical piece parts are so close that new production acceptance techniques must be developed. One such technique is Process Acceptance Technique (PAT) developed by the Sandia Corporation. Pat is based on a standard deviation derived through data obtained from the first 15 parts produced.

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SUMMARY

Product tolerance requirements for small, cylindrical, piece parts produced on swiss automatic screw machines have progressed to the reliability limits of inspection equipment. The miniature size, configuration, and tolerance requirements (plus or minus 0.0001 inch) (0.00254 mm) of these parts preclude the use of screening techniques to accept product or adjust processes during setup and production runs; therefore, existing means of product acceptance and process adjustment must be refined or new techniques must be developed.

The purpose of this endeavor has been to determine benefits gained through the implementation of a process acceptance technique (PAT) to swiss automatic screw machine processes. PAT is a statistical approach developed by Mr. T. P. Conlon of the Sandia Corporation for the purpose of accepting product and centering processes for parts produced by selected, controlled processes. Through this endeavor a determination has been made of the conditions under which PAT can benefit a controlled process and some specific types of screw machine processes upon which PAT could be applied. However, it was also determined that PAT, if used indiscriminately, may become a record keeping burden when applied to more than one dimension at a given machining operation.

DISCUSSION

SCOPE AND PURPOSE

Bendix Kansas City has manufactured small mechanisms containing miniature size, close tolerance product for several years. Swiss automatic screw machines are used to produce many of these parts because of the relatively large production quantities and intricate part configuration. Swiss screw machine processes are very repeatable but many product tolerances (plus or minus 0.0001 inch) (0.00254 mm) approach the reliability limits of production inspection equipment.

Acceptance sampling plans have been developed to maintain acceptable degrees of risk in accepting defective product or rejecting good product. However, no sampling plan including 100 percent inspection is completely reliable because of gage error and inspector fatigue. As the relationship of product tolerance to inspection equipment reliability becomes more critical the chances of rejecting a lot of good product or accepting a lot of defective product is considerably increased. Therefore, a constant awareness of new developments in product acceptance equipment and techniques must be maintained.

A process acceptance technique (PAT) has been developed by Mr. T. P. Conlon of Sandia Corporation. This technique is designed to minimize the risks of accepting bad product and rejecting good product while providing the machine operator with a statistical tool for making tool adjustment decisions and maintaining a properly centered process. PAT also considers gage error and through computed good-bad criteria the working specification limits are reduced to compensate for gaging errors.

Through this endeavor we have attempted to determine the benefits which we might gain through the implementation of a process acceptance plan such as PAT.

ACTIVITY

Several parts made from different materials and produced on various screw machines were studied to obtain a general group of product representative of the Bendix Kansas City total screw machine processes. Standard deviations were established for selected dimensions which were finish machined on the screw machines and a general idea of the types of screw machine product that would be applicable to process acceptance techniques was obtained. A process which has a total of seven standard deviations equal to or less than the specification limit qualifies under PAT criteria. The piece parts under initial evaluation included parts produced on Petermann P7/P7R, Tornos R10, and Tornos RR20 swiss screw machines. These parts were machined from 303 Se stainless steel (annealed condition), 17-4 PH stainless steel (heat treated condition H-900), 304 L stainless steel (annealed condition), beryllium copper (heat treated condition H), and brass (condition 1/2 hard). One part studied was P/N 206381 with three dimensions being evaluated. Two of these dimensions were 0.035 (0.889) plus 0.000, minus 0.001 (0.0254) outside diameters while the third dimension studied was the 0.064 (1.6256) plus or minus 0.001 (0.0254) length. The two diameters are identified as long and short diameters with the short diameter being the front turned diameter while the long diameter was back turned (plunge cut). This part was produced from 303 Se annealed stainless steel on a Tornos R10 swiss screw machine. Table 1 lists for each characteristic include: average, standard deviation, bias between high and low diameter readings (due to taper and out-of-roundness), seven standard deviations using the largest standard deviation for each characteristic, and the minimum product tolerance acceptable for each characteristic to qualify for PAT. The three characteristics considered would qualify for PAT.

Another part evaluated in similar manner was Part Number 262187 which was made from 303 Se annealed stainless steel on a Petermann P7/P7R swiss screw machine. The 0.0295 (0.7493) plus or minus 0.0005 inch (0.01270) front turned diameter was the only dimension studied on this part. There were no tool adjustments or tool changes required throughout the total production of 440 parts. The average diameter of the first 15 parts machined was 0.02955 inch (0.75057) and the standard deviation was 0.00004 (0.0010160) which would require a minimum acceptable tolerance (seven standard deviations) of 0.00028 inch (0.00700) to qualify for PAT. The characteristic considered on this part did qualify for PAT.

The third part studied was Part Number 204474 which was produced from beryllium copper (heat treated condition H) on a Brown and Sharpe #00 screw machine. The characteristic studied was the 0.3162 (8.031480) plus or minus 0.0005 inch (0.01270) turned diameter. The average diameter for the first 15 parts was 0.31604 (8.0274160) with a standard deviation of 0.00005 (0.0012700). The minimum acceptable tolerance for this characteristic would be 0.00035 inch (0.00900); therefore, this part qualified for PAT.

The fourth part studied was Part Number 1440557. This part was produced on a Tornos R10 swiss screw machine from brass rod (condition 1/2 hard). The following three characteristics were monitored: 0.1091 (2.771140) plus or minus 0.0002 inch (0.00508) length, 0.109 (2.76860) plus or minus 0.002 inch (0.0508) front turned diameter and 0.128 (3.25120) plus or minus 0.001 inch (0.0254) back turned diameter. Two different

Table 1. PAT Characteristics for Part Number 206381

Dimension		Average Diameter	Standard Deviation s	Bias	7s	Minimum Acceptable Tolerance
0.035 +0.000 -0.001*	Low	0.03434	0.00004	0.00011	0.00035	0.00046
Short end <	High	0.03435	0.00005			
0.035 +0.000 -0.001	Low	0.03431	0.00012	0.00012	0.00091	0.00103
Long end <	High	0.03443	0.00013			
0.064 ±0.001 Length		0.06405	0.00005	None	0.00035	0.00035

*1 inch equals 25.4 mm

groups of 15 parts each were pulled from the production run of this part for purposes of establishing standard deviations for each characteristic. Table 2 lists the average, standard deviation, bias between high and low readings, seven standard deviations (largest standard deviation), and the minimum tolerance acceptable to qualify each characteristic in the two groups of parts for PAT. Using this criteria all characteristics considered would qualify for PAT.

Four parts and eight characteristics had been studied with all eight dimensions qualifying for PAT. However, all these parts were made from good machining materials with reasonable tolerances.

The next part studied was Part Number 204473 which was machined on a Tornos R10 swiss screw machine from 17-4 PH stainless steel (heat treated condition H-900). Five dimensions were considered for PAT as follows: 0.0277 (0.703580) plus 0.0000, minus 0.0005 inch (0.01270) front turned diameter; 0.0500 (1.270000) plus or minus 0.0015 inch (0.038100) front turned diameter, 0.0277 (0.703580) plus 0.0000, minus 0.0005 (0.01270) back turned diameter, 0.1020 (2.590800) plus 0.0003, (0.00726) minus 0.0000 inch back turned diameter, and 0.1140 (2.895600) plus or minus 0.0007 inch (0.01800) length. Three different groups of parts were measured during the production of this part. The first group consisted of an initial 15 parts used to establish standard deviations and process limits for use in the PAT plans. The results of this first group of parts are shown in Table 3. Four of the five dimensions considered were acceptable for the PAT plans. The 0.0277 inch (0.703580) back turned diameter (plunge cut) was not acceptable since seven standard deviations exceeded the part tolerance.

The next study group of parts was a production run and the operator was instructed to run the parts as he normally would, making tool adjustments and tool changes as he deemed necessary. However, the operator was instructed to check each of the four characteristics being observed on every part and these dimensions were recorded in consecutive order. This was done to simulate PAT and to compare the operator's judgment in adjusting tools to that same judgment obtained through PAT techniques. Through simulation of PAT it was determined that four of the six tool adjustments made by the operator were in agreement with PAT plans. In both instances when PAT judgment and operator judgment differed, the operator made a tool adjustment before PAT plans instructed to adjust. If the operator had been running to PAT instructions, 20 of the 33 parts run would have required screening for an accept or reject decision. About 15 of these parts would have been defective on the 0.1020 (2.590800) plus 0.0003, (0.00762) minus 0.0000 diameter had the operator not made tool adjustments when he did.

Table 2. PAT Characteristics for Part Number 1440557

Dimension	Group	Average	Standard Deviation s	Bias	7s	Tolerance
0.1091 ±0.0002* Length	1 Low	0.10910	0.00004	0.00009	0.00028	0.00037
	1 High	0.10919	0.00003			
	2 Low	0.10909	0.00002	0.00006	0.00014	0.00020
	2 High	0.10915	0.00002			
0.109 ±0.002 Diameter	1 Low	0.10948	0.00004	0.00005	0.00028	0.00033
	1 High	0.10953	0.00001			
	2 Low	0.10957	0.00003	0.00009	0.00021	0.00030
	2 High	0.10966	0.00033			
0.128 ±0.001 Diameter	1 Low	0.12834	0.00006	0.00006	0.00042	0.00048
	1 High	0.12840	0.00006			
	2 Low	0.12813	0.00003	0.00012	0.00028	0.00040
	2 High	0.12825	0.00004			

*1 inch equals 25.4 mm

Table 3. PAT Characteristics of Part Number 204473

Dimension	Average	Standard Deviation	Minimum Acceptable Tolerance
0.0277 +0.0000 -0.0005* Front Diameter	0.02751	0.00004	0.00028
0.0500 ±0.0015 Front Diameter	0.04871	0.00006	0.00042
0.0277 +0.0000 -0.0005 Back Diameter	0.02752	0.00017	0.00119
0.1020 +0.0003 -0.0005 Back Diameter	0.10214	0.00004	0.00028
0.1140 ±0.0007 Length	0.11409	0.00020	0.00140

*1 inch equals 25.4 mm

The third group of parts was produced using PAT to control the four dimensions with satisfactory standard deviations. Table 4 is a list of the tool changes, adjustments, and PAT decision points for this group of parts. There was a production shift change after the 46th part, thus, the need to reach an accept or reject decision on all four characteristics with the 46th part. Beginning with the 47th part the various tool adjustments had to be requalified for the beginning of a new production shift. It was generally agreed among engineering, quality, and manufacturing personnel that a days production should be qualified as accepted or rejected before the hourly personnel's shift change to eliminate confusion between operators. The operator just beginning his work day would then adjust and requalify all tools which finished the previous production shift with a tool adjustment or reject decision. When close, difficult, tolerances are being monitored all tools should be requalified because as a machine sits idle between shifts the bearings and coolant can cool down enough to influence a dimensional change on the first few parts run at the beginning of a new shift. The sampling frequency, listed below each dimension in Table 4, was adjusted to every 10 parts on all dimensions beginning with part number 47. This was done in an attempt to simplify the record keeping problems that can be seen in Table 4. When more than one close-toleranced dimension is being controlled by PAT it becomes increasingly more difficult to maintain the identity of good and bad product. This problem

Table 4. PAT Control of Four Dimensions

	Dimensions (in.) (mm) and Frequency (Hz)			
Part Sequence	0.0277 (0.7035) 20	0.0500 (1.270) 30	0.1020 (2.590) 10	0.1140 (2.895) 15
1	CND	CA	CND	CND
2	CA		CND	CA
3			CND	
4			CND	
5			CND	
6			CA	
7				
8				
9				
10				
11				
12				
13				
14				
15				
16			CND	CA
17			CR	
18			CTA	
19			CTA	
20			CA	
21			(1)	
22				
23				
24				
25	CND		CND	
26	CND		CA	CR
27	CTA		(2)	CTA
28	CND		(2)	CTA
29			(2)	CND
30		CA	(2)	CND
31	TC		(2)	
32	Setup		(2)	
33	TC 0.114		(2)	
34	CTA	CA	(2)	CTA
35	CA		(2)	CA
36			(2)	
37			(2)	
38			(2)	
39			(2)	
40			(2)	CND

Table 4 Continued. PAT Control of Four Dimensions

	Dimensions (in.) (mm) and Frequency (Hz)			
Part Sequence	0.0277 (0.7035) 20	0.0500 (1.270) 30	0.1020 (2.590) 10	0.1140 (2.895) 15
41	CA		CR	CR
42			CTA	CTA
43			CND	CND
44			CA	CND
45				CND
46	CA	CA	CA	CR
47	CTA		TC	TC
48	Setup			
49				
50				
51	CND	CA	CND	CND
52	CND		CND	CND
53	CA		CND	CA
54			CR	
55			CTA	
56			CND	
57			CA	
58				
59				
60				
61				
62				
63				
64	CA	CA	CND	CND
65			CND	CND
66			CTA	(3) CND
67			CA	
68				
69				
70				
71				
72				
73				
74				
75				
76				
77	CA	CA	(3) CND	(3) CND

CA (checked, accepted)
CR (checked, rejected)

CND (checked, no decision)
CTA (checked, tool adjustment)
(1) Sampling frequency changed to every five parts.
(2) Sampling point missed between part 27 and 41; therefore, the tool adjustment was not detected when it should have been.
(3) The process continued because parts were on the low side of the tolerance.

is created because each dimension is normally finished with a different cutting tool and usually a different type of cut, thereby resulting in different rates of tool wear or process control spreads. For instance, of the four dimensions shown in Table 4, each had a different optimum frequency of inspection due to type of cut and process tolerance. The 0.0277 (0.703580) plus 0.0000, minus 0.0005 (0.01270) diameter and the 0.0500 (1.270000) plus or minus 0.0015 (0.038100) diameter were both front-turned with the same cutting tool but because of the large difference in process tolerances, the 0.0500 (1.270000) diameter required much less monitoring than the 0.0277 (.703580) diameter. Reference back to Table 3 will show that the front 0.0277 (0.703580) diameter and the back 0.1020 (2.590800) diameter had identifical standard deviations but because the 0.1020 (2.590800) dimension had slightly more than one half the tolerance of the 0.0277 (0.703580) diameter and because the 0.1020 (2.590800) diameter was plunge cut, it required much more frequent monitoring than the front 0.0277 (0.703580) diameter. Thus, the first disadvantage of PAT is evident. Using PAT to control several dimensions, each with its own optimum frequency of inspection, results in cumbersome record keeping duties for the operator. A possible solution to simplifying the record keeping situation would be to assign a uniform inspection interval for all characteristics being monitored with the interval based on the characteristic requiring the most frequent inspection interval. However, this would obviously result in unnecessary inspection time on all but the one characteristic.

To this point in the study process standard deviations had been determined for several parts with a variety of tolerances, types of cuts, and materials while utilizing all of the swiss screw machines. All products produced on the swiss screw machines have some dimensions which have sufficient process control to qualify for PAT. When comparing operator and PAT decisions to make tool adjustments it was found that four out of six instances PAT and the operator agreed. Of the remaining two adjustments, the operator adjusted before PAT indicated an adjustment was necessary, thus, keeping the dimension within process limits. Had the operator adjusted in these two instances when PAT indicated a necessary adjustment the dimension would have been out of the PAT accept region in both cases and this would have required screening the one dimension on approximately two-thirds of the parts run.

Next, an attempt was made to document the actual time required for production, inspection, engineering and quality personnel to maintain and utilize PAT under actual manufacturing conditions. The first step was to establish contractural guidelines for implementing PAT. Discussions with labor relations personnel brought out of the following points.

- It is almost certain that a grievance would result if acceptance of product was based on readings taken by a machine operator.
- It is recommended that original data used to establish the process standard deviation be taken by a precision layout inspector rather than a mechanical inspector as minor calculations are sometimes required.
- Computation of the process standard deviation should not be performed by hourly personnel.
- The addition to obtain the cumulative sum which is compared to the tabulated good-bad criteria could be performed by a mechanical inspector.

Therefore, in accordance with existing contractual agreements, the application of PAT would require the use of roving floor inspectors.

With these classification guidelines established, we then selected the 0.0932 (2.3672800) plus or minus 0.0001 inch (0.0025400) turned diameter on Part Number 292247 for the time comparisons. This part was made from 304L stainless steel material on a Tornos RR20 swiss screw machine. To begin the study 15 parts were turned and placed in a box, maintaining the machining sequence. These parts were to be used to establish a process standard deviation and tabulated good-bad criteria. An inspector checked and recorded the actual size of the 0.0932 inch (2.3672800) diameter on each of the 15 parts using a bench micrometer and master at the machine area. The inspector required 30 minutes to master the bench micrometer, check the 15 diameters and record the actual size of each diameter. The inspector was summoned at the beginning of production of the initial 15 parts, but he did not arrive until approximately 5 minutes after the 15 parts were completed. Thus, the machine operator stood idle 35 minutes waiting for the inspector to arrive and check the parts. Once these parts were checked and the data recorded, this information was then delivered to a quality control statistician for calculation of the process standard deviation, regression of tool wear and assemblance of good-bad criteria on to forms usable in the machining area. It required 2 hours of the statisticians time to do all this and get the completed forms to the machining area by delivering them himself. The machine operator also remained idle for this 2 hour period. However, it should be noted that the process standard deviation, regression of tool wear, and good-bad criteria are all established at the beginning of the initial production schedule. Subsequent recalculation of this data should not be necessary until there are process or part print changes. With the process standard deviation for the 0.0932 inch (2.3672800) characteristic being acceptable for PAT and having the good-bad criteria available, we then proceeded to produce a total of 225 parts depending entirely on PAT criteria for tool adjustment and accept-reject decisions for each lot of parts produced. This production run involved several different shifts of production operators. During the production of these 225 parts, the actual size of the 0.0932 inch (2.3672800) diameter was recorded for each part and this data, along with each part was identified in the order it was machined. This was done not only to screen the defective parts from the rejected lots, but also to provide reference gage readings which could be compared to those readings taken later by inspection personnel on these same parts using Production's gage and master. This comparison would indicate gage repeatability.

When the production run was completed, a mechanical inspector inspected the parts using Production's bench micrometer and master. We designated the inspection interval or lot size as 50 parts and asked the inspector to select the parts to be checked from a table of random numbers. The inspector then measured the selected parts in each of the five lots until an accept or reject decision was obtained using the same good-bad PAT criteria used by Production (Table 5). Twenty-one parts were inspected before all five lots totaling 225 parts, were accepted and this required a total of 65 minutes of inspection time.

The designated inspection interval was then changed to the end of each production shift. This was the interval recommended by the Bendix Kansas City Quality Division and it would require an inspector to go to the machine area at the end of each shift, pull a sample, and accept or reject the ending shift's total production. The lot sizes and results for this inspection interval are recorded in Table 6. Twenty-seven parts were inspected before all six lots totaling 225 parts were accepted and this required a total of 67 minutes of inspection time.

Table 5. PAT Criteria Used by Production

Lot	Number	Part Number	Diameter (Inches)	PAT Decision	Inspection Time Required (Minutes)
1	1-50	29	0.09320*		
		5	0.09331	ND**	
		24	0.09324	ND	
		47	0.09329	ND	
		39	0.09322	ND	
		16	0.09327	ND	
		14	0.09324	ND	
		42	0.09327	ND	
		32	0.09323	ND	
		9	0.09319	Accept	35
2	51-100	83	0.09327		
		79	0.09316	Accept	5
3	101-150	123	0.09318		
		128	0.09326	Accept	5
4	151-200	152	0.09314		
		161	0.09328	Accept	5
5	200-225	214	0.09317		
		201	0.09332		
		221	0.09326		
		212	0.09327		
		216	0.09317	Accept	15

*1 inch equals 25.4 mm

**No decision

Table 6. Results of Inspection Interval

Lot	Number	Part Number	Diameter (Inches)	PAT Decision	Inspection Time Required (Minutes)
1	1-30	22	0.0321*	ND**	
		16	0.09327	ND	
		5	0.09330	ND	
		27	0.09324	ND	
		10	0.09322	ND	
		1	0.09327	ND	
		12	0.09324	ND	
		15	0.09324	ND	
		3	0.09324	ND	
		8	0.09317	Accept	30
2	31-63	61	0.09330		
		32	0.09324	ND	
		43	0.09320	ND	
		31	0.09322	Accept	10
3	64-115	76	0.09325		
		112	0.09326	ND	
		87	0.09322	ND	
		89	0.09323	Accept	10
4	116-174	148	0.09315		
		165	0.09317	ND	
		162	0.09317	Accept	5
5	175-210	177	0.09314		
		197	0.09317	ND	
		202	0.09330	Accept	5
6	211-225	211	0.09322		
		225	0.09324	ND	
		215	0.09318	Accept	7

*1 inch equals 25.4 mm
**No decision

The inspector was then instructed to select 15 parts using the table of random numbers and inspect the parts as he normally would, treating the total 225 parts as one lot and using a sampling plan with n=15. All 15 parts checked good and the lot of 225 parts was accepted, using 25 minutes of inspection time. However, if one defective part had been among the 15 sampled, all 225 parts would have required screening for acceptance. It would have required approximately 6 hours of inspection time to screen all 225 parts.

ACCOMPLISHMENTS

All parts produced on our screw machines have some dimensions which have a process standard deviation/process specification limits relationship that is acceptable for PAT applications.

In general, the minimum product tolerance limits which would qualify under PAT criteria are

- 0.0003 inch (0.00762) on diameters turned in reasonably good machining materials (303 or 304L stainless steel and brass),
- 0.0005 inch (0.01270) on diameters turned in more difficult machining materials (17-4 Ph stainless steel), and
- 0.0004 inch (0.01016) on length dimensions.

There are instances when closer tolerances may qualify for PAT but these would have to be qualified on an individual basis. Diameters finished with a back turn or plunge cut, would also require individual consideration.

PAT techniques have a distinct advantage over present Bendix Kansas City acceptance procedures in that PAT plans require the production operators and inspectors to use the same acceptance gage and master, thereby reducing gage error.

PAT is advantageous as an in-process inspection, thereby rejecting defective product before it is moved on to secondary machining operations.

Product priority is maintained through manufacturing and inspection by the same AMPS document.

Implementation of PAT will result in fewer parts inspected (than present sampling plans using n=15) if the following general rules apply.

- Product that requires no tool adjustments during the entire production quantity will have no more than four PAT inspection intervals.

- For product requiring a tool adjustment at the beginning of each production shift, the number of parts inspected for PAT would exceed 15 parts during the third production shift. Thus, if three or more production shifts were required to complete the total schedule release, then PAT would result in more parts inspected.

- Product requiring more than one tool adjustment within a production shift would result in more parts inspected using PAT at the third tool adjustment.

PAT may reduce the amount of screening that is required providing the product being manufactured meets the requirements (seven standard deviations equal or less than the product tolerance) and is properly centered within the part tolerance interval. However, this is true for any sampling plan if the percent of product out of specification limits is small enough. When the product becomes marginal (that is, when the product average shifts within the production run or the process standard deviation increases) the lots being rejected must either be discarded or screened. Even though the screening is not 100 percent efficient it does reduce the amount of defective product going to the next production operation.

PAT is reasonably simple to apply when only one characteristic is being monitored. However, record keeping becomes more cumbersome as PAT is applied to multiple dimensions and as the relationship of seven standard deviations to the specification limits become closer.

PAT is based on a standard deviation through data obtained from the first 15 parts produced. The first few parts produced on a machine setup are machined with all new sharp cutting tools. A standard deviation may change as the cutting tools go through their wear pattern and as new cutting tools and different pieces of bar stock are introduced into the machine setup. Thus, the initial standard deviation may not be representative of the total process. Therefore, a monitoring system should be established to constantly evaluate the standard deviation and update the inspection frequencies.

PAT will result in more engineering and quality control time than present inspection procedures. The amount of time required of each group would depend on guidelines established when implementing PAT. That is, who would collect inspection data, calculate standard deviation, tool wear regressions and good-bad criteria, who would transfer this data to forms for production use and who would monitor and update the system throughout the total production schedules. Two hours are required to calculate standard deviations, tool wear regressions and good or bad criteria.

Because PAT lots are generally smaller than (n=15) inspection lots, fewer parts would have to be screened in the event a PAT lot was rejected as opposed to the number of parts to be screened, should a normal lot be rejected.

From quality histories, it does not appear that rejection of entire lots of product using n=15 sampling plan has been a frequent problem. In instances where a particular dimension is frequently defective using n=15 sampling, it is probable that this dimension would not have a standard deviation that would qualify under PAT criteria.

The present acceptance procedure could be improved considerably by requiring production and inspection personnel to use the same acceptance gage and master. This would be especially beneficial when inspecting specification limits of 0.0005 inch (0.01270) and closer.

FUTURE WORK

PAT will be applied to mutually agreed (Sandia/Bendix) piece parts and will be initiated by applying to single parameter controlled piece parts under production conditions. Implementation and monitoring procedures shall be documented to further determine PATs overall effect.

PAT could not be recommended for reduction of inspection time if more than four inspection intervals were required to accept the total production quantity. Generally, the ratio of inspection intervals to production quantities would exceed four.

The present acceptance procedure for close toleranced dimensions would benefit considerably if production and inspection personnel used the same acceptance gage and master.

If an in-process control procedure was desired for reasons other than reduction of inspection, then it appears these controls could be obtained through the use of $\overline{X}$ and R charts. These control charts are easier to understand and monitor in a production environment than a statistical approach such as PAT.

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