SPC Acceptance of Hobbing & Shaping Machines

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Today, as part of filling a typical gear hobbing or shaping machine order, engineers are required to perform an SPC acceptance test. This SPC test, while it is contractually necessary for machine acceptance, is not a machine acceptance test. It is a process capability test. It is an acceptance of the machine, cutting tool, workholding fixture, and workpiece as integrated on the cutting machine, using a gear measuring machine, with its work arbor and evaluation software, to measure the acceptance elements of the workpiece.

Depending on the workpiece tolerances and desired capability (Cpk level), this acceptance test can be a relatively simple runoff, or it can be a long, complicated procedure to determine the source of variables in the system.

Rarely is the hobbing or shaping machine a sensitive element in the acceptance process. Fig. 1 shows the relative weighting of the critical elements of the system in a gear hobbing or gear shaping machine.

Usually, in the proposal stage for a machine order where SPC requirements are defined, American Pfauter engineers reverse-engineer all critical elements of the system to establish if the desired Cpk can be achieved. Often, at first glance, workpiece production tolerances shown on the workpiece drawing are practically achievable. But when the capability indexes are greater than 1.0, the reduction of the allowable values often reveals tolerances which are not readily achievable. In some cases the centering of the average value for a plus/minus 3σ requirement exceeds the achievable accuracies of the generating process. This is typically seen when attempting to conduct an SPC qualification for workpieces which will be subsequently finished by another process, where productivity feeds and speeds alter tooth topography to a

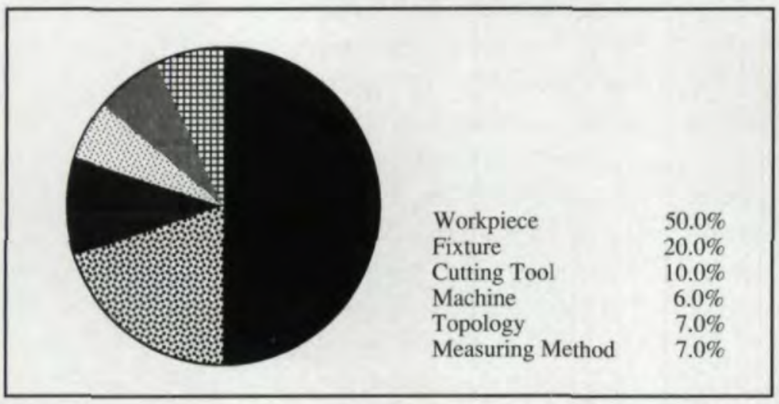


Fig. 1 - Relative weighting of the critical elements of the system in a typical gear hobbing or shaping 6 Sigma machine acceptance for size, lead, and runout criteria. Involute and spacing (pitch) are usually excluded as criteria for pre-shave and pre-roll gear operations, but included as criteria for finished hobbed and shaped operations. The element labelled "Topology" refers to the flank topology of a gear tooth as produced by the feed of the cutting tool and, in the case of hobbing, to the number of threads in the hob.

Fig. 2 - Gear tooth flanks produced by high feed rate, multi-thread hobbing.

level which belabors interpretation in the analytical inspection process. Fig. 2 shows the flanks of gear teeth hobbed for subsequent shaving using high feed rates and a multiple thread hob.

Fig. 3 shows the flanks of teeth shaped by the CCP method for subsequent shaving.

In general, CNC gear hobbing and gear shaping machines manufactured today already must pass a series of static and dynamic alignment and kinematic tests to be considered ready-to-cut workpieces. Figs. 4a and b illustrate 10 of the 19 acceptance checks for a gear hobbing machine according to DIN 8642 standards.

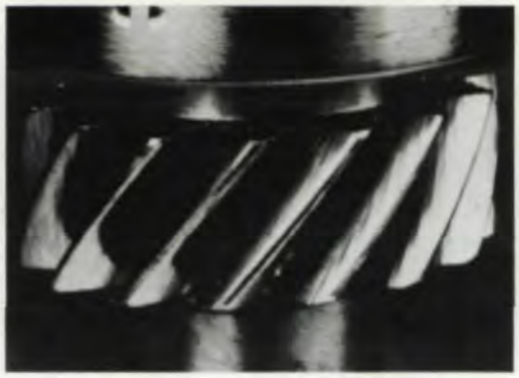
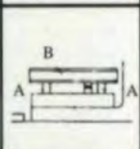
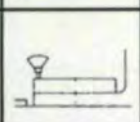
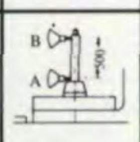
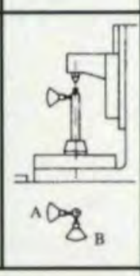


Fig. 3 - Flanks of gear teeth shaped by the CCP high-feed-rate method for subsequent shaving.

Standards of Acceptance for Hobbing Machine P1251 (in accordance with DIN 8642) with Special Accuracy					TR-73
Serial No:			Consignee:		
Check	Illustration	Measuring tools	Permissible deviation	Measured deviation	Procedure
1 Flatness of table top		Gage blocks Straight edge	+0,035 mm	+0,035	Place straightedge B on two gage blocks A of identical length on table top. Measure distance from table top to straightedge by inserting gage blocks. The table top must not be crowned (convex).
2 Parallelism between table top and column guideway		Gage blocks Straight edge Comparator	-0,020 mm per 1000 mm	-0,02	Place straightedge B on two gage blocks A of identical length on table top. Position comparator on hob head, contact point on straightedge. Displace column over full length of travel and note comparator reading.
3 True running of table top		Comparator	0,020 mm	0,015	Position comparator on table top (at d = 1120mm) Rotate table slowly and note comparator readings.
4 Concentricity of work arbor		Comparator	A 0,005 mm B 0,015 mm	A 0,005 B 0,008	Position comparator on circumference of work arbor. Rotate table slowly and note comparator readings. Take measurement A near cone.
5 Alignment of work arbor and support arm (tailstock) center		Comparator	A 0,015 mm B 0,015 mm	A — B —	Position comparator on circumference of work arbor directly in front of support arm. Rotate work arbor to central position of concentricity error. Note comparator readings with support arm retracted and applied.

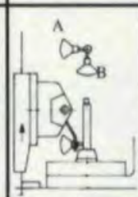
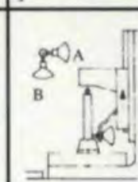
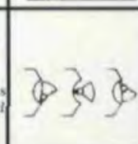
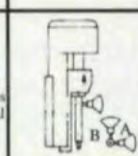
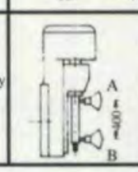
Standards of Acceptance for Hobbing Machine P1251 in accordance with DIN 8642) with Special Accuracy					TR-73
Serial No:			Consignee:		
Check	Illustration	Measuring tools	Permissible deviation	Measured deviation	Procedure
6 Parallelism between work arbor and hob slide guideway		Comparator	A +0,025 mm B 0,015 mm	A + 0,018 B 0,01	Position comparator on hob head,contact point on circumference of work arbor. Rotate work arbor to central position of concentricity error. Displace hob slide over full length of travel and note comparator readings.
7 Parallelism between work arbor and support arm guideway		Comparator	A +0,020 mm B 0,020 mm	A + 0,015 B 0,02	Position comparator on support arm. Position comparator on circumference of work arbor. Rotate work arbor to central position of concentricity error. Displace support arm slide over full length of travel and note comparator readings.
8 Parallelism between counter bearing recess and tangential slide guideway		Comparator	0,010 mm per 100 mm	0,008 0,01 0,008	Position comparator on bearing recess. Displace tangential slide and note comparator readings.
9 Parallelism between counter bearing recess and tangential slide guideway		Comparator	A 0,010 mm B 0,010 mm	A 0,008 B 0,008	Position comparator on circumference of work arbor. Rotate work arbor to central position of concentricity error. Displace tangential slide over full length of travel and note comparator readings.
10 Concentricity of hob arbors		Comparator	A 0,005 mm B 0,008 mm	A 2" / 0,004 2" / 0,003 B 2" / 0,008 2" / 0,008	Position comparator on circumference of work arbor. Rotate hob spindle slowly. Take measurement A near cone.

Fig. 4a - Standards of acceptance for a hobbing machine (DIN 8642). Tests 1-5. Fig. 4b - Standards of acceptance for a hobbing machine (DIN 8642). Tests 6-10.

SPC engineers, however, attempt to accept a hobbing or shaping machine through the statistical evaluation a process by checking the product it produces without identifying the inherent variables. Often these attempts become excruciating trials due to:

a) arbitrary product or process specifications,

b) arbitrary component specifications,

c) out-of-control process, materials, and equipment,

d) inadequate evaluation and inspection system,

e) little understanding of gear manufacturing processes.

A typical example is the gear manufacturer who expects an SPC acceptance test to a Cpk of 1.67 on a gear designed to AGMA Class 9 tolerances, yet supplies workpiece

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TABLE 1						
EFFECT OF SPC ON AGMA QUALITY 9 TOLERANCES (ANSI/AGMA 2000-A88)						
GEAR DATA:	18 TEETH		16.933 NDP			
	25.8419° HA		.9483" FW			
	1.1811" PD		STD GEOMETRY, NO MODIFICATIONS			
			VwT	VoT	VrT	VpA
AGMA TOLERANCE (tenths)			0.0004	0.00046	0.0011	0.00082
	SAMPLE SIZE	% TOL.				
CPK 1.33	25	49.1	0.0002	0.00023	0.00054	0.0004
EQUIV. AGMA Q#			13	12	12	12
CPK 1.67	25	39.3	0.00016	0.00018	0.00043	0.00032
EQUIV. AGMA Q#			14	12	12	12
CPK 2.0	25	32.8	0.00013	0.00015	0.00036	0.00027
EQUIV. AGMA Q#			14	13	13	13
NOTE: All statistics based on unbiased estimate of SD(X)=R/d2						

TABLE 2						
EFFECT OF REDUCED SAMPLE SIZE (PART-TO-PART) ON AGMA QUALITY 9 TOLERANCES ON GEAR DATA IN TABLE 1						
GEAR DATA:	18 TEETH		16.933 NDP			
	25.8419° HA		.9483" FW			
	1.1811" PD		STD GEOMETRY, NO MODIFICATIONS			
			VwT	VoT	VrT	VpA
AGMA TOLERANCE (tenths)			0.0004	0.00046	0.0011	0.00082
	SAMPLE SIZE	% TOL.				
CPK 1.33	2	14.1	0.00006	0.00006	0.00015	0.00012
EQUIV. AGMA Q#			>15	15	15	15
CPK 1.67	2	11.3	0.00005	0.00005	0.00012	0.00009
EQUIV. AGMA Q#			>15	>15	>15	>15
CPK 2.0	2	9.4	0.00004	0.00004	0.0001	0.00008
EQUIV. AGMA Q#			>15	>15	>15	>15
NOTE: All statistics based on unbiased estimate of SD(X)=R/d2						

TABLE 3						
EFFECT OF SPC ON AGMA QUALITY 9 TOLERANCES (ANSI/AGMA 2000-A88)						
GEAR DATA:	96 TEETH		5.08 NDP			
	16.2602° HA		1.9685" FW			
	19.68" PD		STD GEOMETRY, NO MODIFICATIONS			
			VwT	VoT	VrT	VpA
AGMA TOLERANCE (tenths)			0.00065	0.0012	0.00383	0.00177
	SAMPLE SIZE	% TOL.				
CPK 1.33	25	49.1	0.00035	0.00059	0.00188	0.000087
EQUIV. AGMA Q#			12	12	12	12
CPK 1.67	25	39.3	0.00026	0.00047	0.00151	0.00069
EQUIV. AGMA Q#			14	12	12	12
CPK 2.0	25	32.8	0.00021	0.00039	0.00126	0.00058
EQUIV. AGMA Q#			14	13	13	13
NOTE: All statistics based on unbiased estimate of SD(X)=R/d2						

Tables 1, 2, 3 - The effect of SPC on AGMA Quality 9 tolerances. (ANSI/AGMA 2000-A88)

Legend: VwT = Tooth alignment (lead)
VoT = Profile
VrT = Radial runout
VpA = Pitch

blanks at production tolerances, which may not comply to print specifications (Cpk 1.0) on characteristics, such as bore-to-face perpendicularity and bore size, and which have no tolerance or definition for bore cylindricity, bore roundness, or bore taper. Further, he demands maximum productivity and insists on multi-thread hobs working at high feed rates. (See Tables 1, 2, and 3.)

The inherent system variables in the gear manufacturing process (see Table 4) can make it difficult to achieve the desired capability for lead and involute, depending on the specification width.

For workpiece/workholding repeatability, these inherent variables can be implied from the following statements:

1) The actual machine workholding axis of rotation must be identical to the actual axis of workpiece rotation.

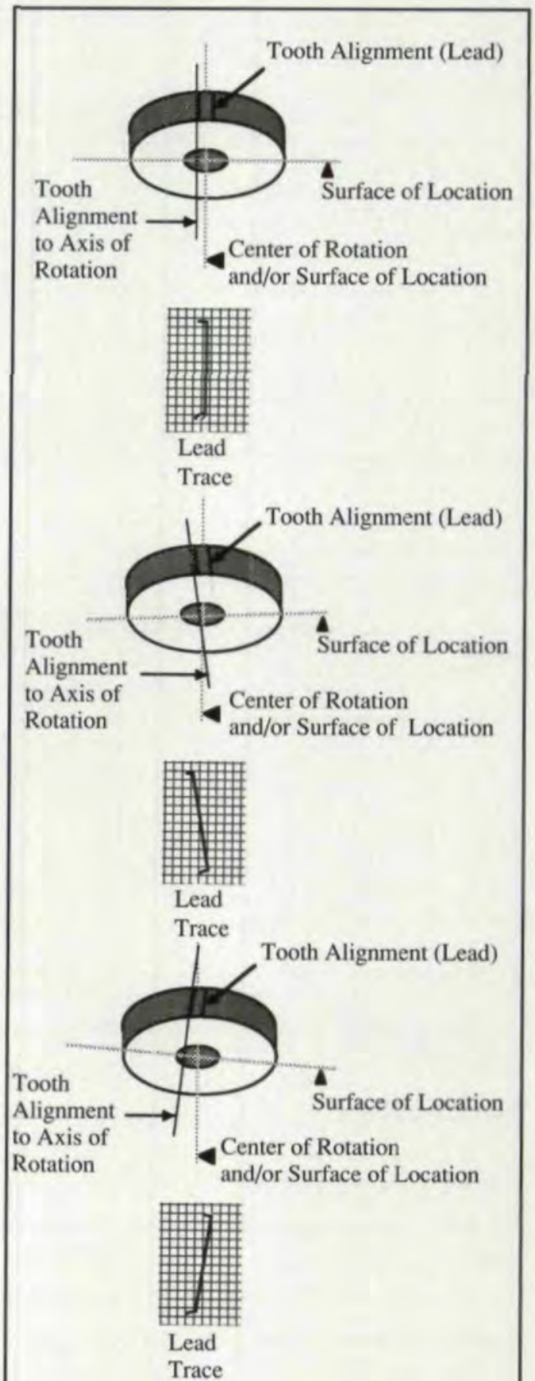


Fig. 5 - The effect of axial face runout on lead variation on a clamped workpiece.

2) Workpieces whose critical locating elements have not been identified and qualified to a compatible capability level will cause the statistical evaluation to fail. Bore geometry variation impacts lead, involute, and radial runout error.

3) Little bore geometry error means less lead, involute, and radial runout variation.

4) Little axial face runout error means less lead, involute, and radial runout error. Fig. 5 illustrates the effect of face wobble in determining lead variation.

5) Greater bore geometry error means less contact between the machine workholding fixture and the actual bore of the gear.

6) Less contact between machine workholding and the actual bore of gear means greater lead, involute, and radial runout variation.

7) Less random variation of number and magnitude of bore geometry errors from part to part and throughout a given sample of parts means lead, involute, and radial runout variation shall be in "statistical control."

8) A greater random variation of number and magnitude of bore geometry errors from part to part and throughout a given sample of parts, means lead, involute, and radial runout variation shall be less "statistically capable."

For inspection workpiece/workholding repeatability these inherent variables can be implied from the following statements:

1) At best, inspection workholding "approximates" the machine workholding axis of rotation.

2) There is always a difference between machine workholding and inspection workholding, which means that the axis of workpiece rotation and the axis of inspection rotation cannot be identical.

3) Greater random variation of number and magnitude of bore geometry errors from part to part and throughout a given sample of parts means greater difference between machine workholding and inspection workholding, which means lead, involute, and radial runout variation will be less "statistically capable."

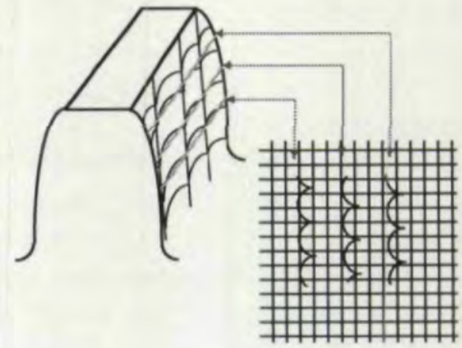
4) Inspection machine software, designed to draw the average trace of leads on four teeth 90° apart and using the sum-of-least-squares method, can show random lead

Table 4 - Sources of gear element errors.

GEAR ELEMENT	POSSIBLE SOURCE
Tooth Alignment (VwT) (lead)	Machine static alignments Machine thermal stability Electronic synchronization values Tool wear (built-up edges) Measuring machine alignments Measuring machine evalution software routines
Tooth Alignment (VwT)-variations within a single workpiece	Work fixture arbor radial runout Axial face runout of workpiece "Arborology" (How the arbor fills the bore) Measuring machine arbor radial runout Transfer error between clamping on cutting arbor and measuring arbor Guide looseness (shaper) Feed rates, hobbing/shaping conditions Number threads in hob Tooth topography. (Fig. 7)
Profile (VoT)	Hob number of threads Hob shift variation effect Hob rack form Hob lead (in one turn of helix) Hob mounting on hob arbor Face runout of workpiece Electronic synchronization resolution Work fixture arbor radial and axial runout Feed rates Tooth topography. (Fig. 7) Hob built-up edges
Radial runout (VrT)	Work fixture arbor radial runout Workpiece bore size to arbor differential (solid arbor) Workpiece bore cylindricity "Arborology" (How the arbor fills the bore) Measuring machine arbor radial runout Transfer error between clampings on cutting arbor and measuring arbor

Pitch (VpA)	Machine worktable drive Electronic drive resolution Feed rates Number of threads in hob Flank topography "as seen" by measuring machine probe

Size	Machine X-axis setting Thermal machine growth Hob flute resharpening accuracy Hob thread-to-thread error Feed rates - hobbing /shaping conditions Measuring technique



Lead topography as seen by three traces on a helical gear hobbed at high feed rate

Fig. 7 - Tooth topography showing three lead possibilities a measuring probe might "see." With reference to Fig. 6 and the introduction of hob thread-to-thread errors to the lead trace, which the *measuring probe "sees," further opportunity is* provided for incorrect evaluation of the lead.

variation on flanks hobbed with multi-thread hobs when the workpiece blanks show little bore geometry and axial face runout error. (See Fig. 6.)

Most manufacturers purchasing machines dedicated to a specific workpiece are naturally interested in qualifying the system to a specific specification. Once that specification is achieved, changing it to a higher requirement at a later date may make the process no longer capable.

For manufacturers purchasing machines to produce several parts to various specification levels, the machine system capability demonstrated on the acceptance workpiece may not be attainable on another workpiece at another specification level.

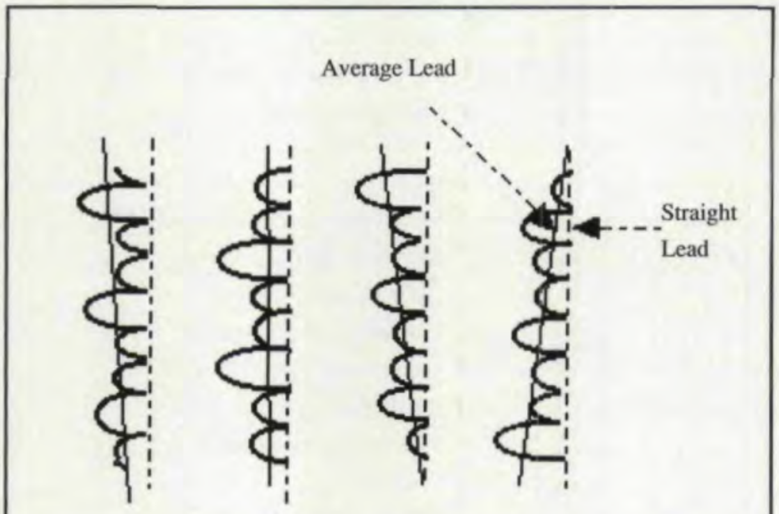


Fig. 6 - Effect of multi-thread hob, thread-to-thread error on average lead value as measured on four teeth 90° apart. Spiral progression of feed rate and thread error alters average lead, even though the lead is straight.

Manufacturers who purchase brand new equipment for hobbing or shaping gears cannot expect significant improvement in the quality capability of the new process over the old process if they do not improve the prior operations and part geometry specifications involved in the blanking of the workpieces for the hobber or shaper.

Manufacturers who purchase brand new hobbing machines and shaping machines with a specification level of 2.0, tight production tolerances, and low piece number qualification samples should not expect the new machinery necessarily to give them a productivity improvement. Capability indexes greater than 1.0 against stringent tolerance fields on all gear elements severely constrain the gear manufacturing process in the name of statistical control when, in reality, the application of SPC to analytical inspection methods may have no functional validity. In such cases, for hobbing and shaping, an application of common sense is usually necessary. ■

Acknowledgement: *Presented at the AGMA Gear Manufacturing Symposium, April 7-9, 1991, Chicago, IL and at an SME Gear Clinic. Reprinted with permission.*