vetcnc
CNC MANUFACTURING

ENGINEERING RESOURCES / 09

CNC Tolerances & Fits

Inspection Planning in Practice

Define the interface.
Control the variation. Verify the decision.

01 — **FUNCTION**
What must work

↓

02 — **LIMITS**
What can vary

↓

03 — **METHOD**
What is measured

↓

04 — **DECISION**
How it is judged

CONTROL THE INTERFACE

WORKED TOLERANCE CASE

DATUM + MEASUREMENT LOGIC

FILLABLE FORMS

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START HERE

Make variation serve the function

A practical guide to tolerances, fits, datums and inspection planning for CNC parts.

A drawing is not improved merely because every dimension has a tighter number. A useful requirement says what interface must work, which variation threatens that function, what references locate the feature, and how the result will be verified and decided. The best starting point is the mating condition, not a familiar tolerance code.

Read before copying any example

LX-62, all dimensions, limits, calculations, diagrams and worksheets are fictional teaching material. They are not Vetcnc production data, a universal fit recommendation or a substitute for your released drawing. Check the complete mating stack, material state, coating, temperature, load, assembly force, safety and customer requirements with the responsible engineering authority.

> **WHAT THIS GUIDE DOES NOT DO**
>
> It does not reproduce licensed standards or fit tables, certify a drawing, approve a tolerance, establish a default acceptance rule, or authorize product release. Safety-critical, regulated, medical, aerospace and other high-consequence products need their applicable controlled processes and qualified review.

01 / FUNCTIONAL REQUIREMENT

Begin with the interface, not the number

Variation matters only through the way a part is assembled, loaded, located, sealed, moved or measured.

FUNCTION	VARIATION	CONTROL	EVIDENCE
What must work	What can change	What is specified	What is verified

Start with the interface function; use a limit only when it protects a known condition.

For each critical interface, state the job in ordinary language first: locate a housing repeatably; allow a pin to enter without damage; prevent rotation; keep an o-ring land continuous; maintain a sensor gap; or let a cover fasten without bending. Then list the physical conditions that change the job: two mating parts, temperature, coating, torque, lubricant, debris, wear, load direction, service cycles and permitted assembly method.

Function question	Requirement consequence	Evidence to request
What must move or locate?	Clearance, position, orientation or surface condition may matter more than a nominal size.	Mating drawing/model, assembly sequence and allowable force.
What must not happen?	Interference, rocking, leakage, binding, excessive play or wrong clocking may require distinct controls.	Failure mode, functional test or controlled prior design basis.
In what delivered state?	Finish, burr removal, coating, heat treatment and cleanliness can change the effective interface.	Final-state definition and process sequence.
How will it be judged?	A feature needs a method, fixture/datum strategy, record and decision rule.	Inspection plan, report format and acceptance authority.

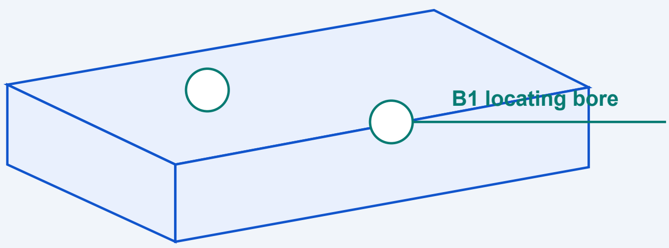
FUNCTIONAL LANGUAGE IS A DESIGN INPUT

“Precision” and “standard fit” are not functional requirements. They conceal the allowed movement, environment and verification method that a supplier needs to quote, manufacture and inspect consistently.

02 / WORKED CASE

Work the LX-62 case without treating it as a rule

A fictional locating plate shows how a requirement can be decomposed before a fit code is chosen.



LX-62 / LOCATING PLATE

6061-T6 aluminum
Two customer-specified pins
B1: 8.000 to 8.012 mm
after agreed final state

Explanatory schematic, not a drawing.

LX-62 is a fictional 6061-T6 aluminum locating plate for non-safety-critical indoor equipment. A removable cover uses two customer-specified stainless-steel dowel pins for repeatable location; screws provide clamp load. The illustrative plate requirement states a final bore B1 of 8.000 to 8.012 mm after the agreed finishing sequence. The customer-supplied pin certificate range is 7.994 to 7.998 mm. These values are original examples, not an ISO-code translation.

Case fact	Why it is controlled
B1 locating bore	A pin locates the cover; bore size, bore axis, bore position and entry condition can each affect assembly.
Customer pin	The pin range is an interface input. It must not be silently replaced by a nominal 8 mm pin.
Two-pin pattern	Second-pin location can create a pattern mismatch even when each bore looks acceptable alone.
Final condition	Any coating, anodize, debris, burr or masking constraint must be stated before the bore limit is released.
Decision	The live drawing, agreed inspection method and decision rule decide conformity. This case only demonstrates planning.

The team should next ask whether B1 is a clearance feature, a locating feature, a retention feature or more than one. That answer determines what must be limited. A nominal diameter alone cannot communicate how the two-pin cover will behave when parts are at their allowable extremes.

03 / REQUIREMENT ARCHITECTURE

Separate size, form, orientation and location

A measured diameter can be in range while the interface still fails because another characteristic is uncontrolled.

SIZE	FORM	ORIENTATION	LOCATION
How big?	What shape?	Which direction?	Where relative?

A diameter result can pass while another characteristic still prevents functional assembly.

Size controls how large or small a specified feature is under the agreed definition. Form controls whether the feature shape is acceptable. Orientation controls its angular relationship to a reference. Location controls where it is relative to the intended references. Surface texture, edge condition, material state and finish can also change the function. These are complementary requirements, not substitutes for one another.

Observed assembly symptom	Question before adding a tolerance
Pin enters only when cover is rotated	Is bore-to-bore position, datum selection, pin straightness, cover pattern or assembly sequence responsible?
Pin starts but binds at depth	Is bore axis orientation, bore form, coating build, burr, contamination or actual pin geometry involved?
Cover has unwanted play	Is the allowable clearance, pin range, bore size, wear expectation or clamp strategy too permissive?
Fasteners pull the cover into position	Are screws compensating for a locator mismatch? Do not infer this is acceptable without the functional authority.

Use the characteristic that corresponds to the failure mode. Tightening a diameter in response to a location problem can raise cost without improving assembly. Conversely, adding a geometric callout without a functional datum scheme can make inspection elaborate while leaving the real interface unclear.

Sources: [04] ISO | [06] ISO | [07] ISO

04 / DATUMS

Choose the datum strategy from how the part works

A datum scheme is an agreed way to establish references for design communication and verification, not decoration on a drawing.

DATUM SIMULATION

A: seating face
B: long edge
C: end edge

Functional contacts must be confirmed by the drawing owner.

For LX-62, imagine a stable mounting face as datum A, a long locating edge as datum B and a perpendicular edge as datum C. The drawing owner must decide whether those are functionally relevant contact references, how the part is seated, and whether the same simulation can be achieved in inspection. A coordinate origin selected for convenient CAD modeling may not be the right assembly reference.

Datum planning question	Why it changes the result
What contacts first in assembly?	Primary contact constrains the most motion and may need to be simulated consistently.
Which reference sets left-right and fore-aft location?	Secondary and tertiary references influence how the hole pattern is located.
What is actually stable in inspection?	Fixture support, clamp force and contact condition can distort or reposition a thin part.
Is the datum feature itself controlled?	A warped mounting face or damaged edge can make a downstream location result meaningless.

DO NOT INVENT DATUM EQUIVALENCE

A CMM alignment, a vise stop and the final mating housing can be related, but they are not automatically identical. Document the setup and verify that it represents the intended functional decision.

Sources: [03] ISO | [04] ISO

05 / SIZE CONTROLS

Specify a linear size with its meaning intact

A numerical limit needs an unambiguous feature definition, state of delivery and measurement context.

Before writing a bore size, identify the feature: cylindrical bore, reamed hole, counterbore, slot width, wall thickness, distance between surfaces, or a functional diameter defined through a specified method. State whether the requirement is before or after finishing, which unit system controls, and which other features establish the location. The same printed number can mean very different things when attached to different feature definitions.

Requirement phrase	What may still be missing
“8 mm hole”	Limits, feature extent, final condition, location, edge condition and verification method.
“8.000 to 8.012 mm”	Whether the complete feature must satisfy it, how form and axis are controlled, and the delivery state.
“Match mating pin”	Actual pin range, mating quantity, assembly clearance, environmental state and decision owner.
“Use H7”	The basic size, the controlled edition/table, shaft/mating condition, material/process and functional justification.

ISO linear-size standards establish notation and definitions, but do not turn an unstated assembly function into a complete requirement. If a code system is contractually invoked, identify the full applicable standard, edition, basic size, mating specification and any stated exceptions. Do not copy a code from a chart without confirming those inputs.

KEEP THE ORIGINAL SOURCE LICENSED

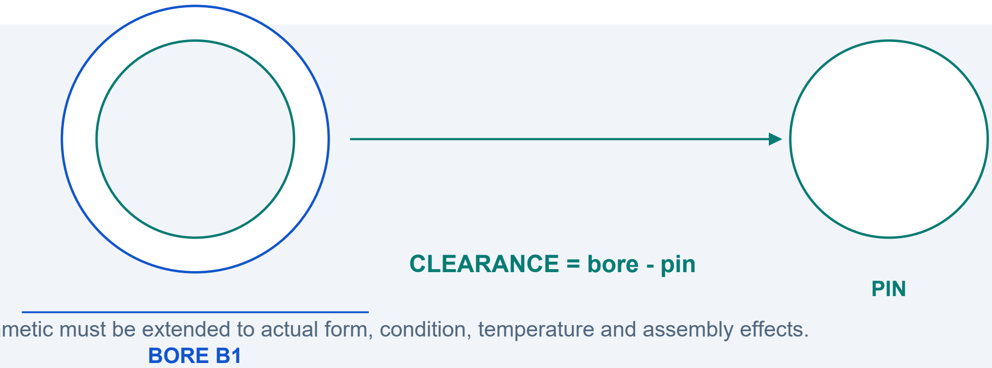
This guide describes a planning method only. Consult the licensed or authorized standard and the released product requirement for values, limits, modifiers and interpretation.

Sources: [01] ISO | [02] ISO | [06] ISO | [07] ISO

06 / FITS

Treat a fit as an interface calculation

A fit is the combined behavior of mating features at their permitted extremes, not a label attached to one part.



Illustrative arithmetic must be extended to actual form, condition, temperature and assembly effects.

For the LX-62 illustration, clearance equals the measured bore size minus the measured pin size. Using only the stated fictional extreme ranges, the minimum possible clearance is 8.000 - 7.998 = 0.002 mm. The maximum possible clearance is 8.012 - 7.994 = 0.018 mm. This arithmetic is valid only for the simplified dimensions shown; it does not include bore form, pin straightness, coating, temperature, contamination, datum effects or assembly force.

Check at each extreme	Illustrative result
Smallest permitted bore minus largest permitted pin	8.000 - 7.998 = 0.002 mm clearance.
Largest permitted bore minus smallest permitted pin	8.012 - 7.994 = 0.018 mm clearance.
One measured build: B1 8.009 mm, pin 7.996 mm	8.009 - 7.996 = 0.013 mm actual size-only clearance.
What this does not decide	Whether 0.002 mm is assemblable, durable, economical or appropriate for this product.

Write the assembly objective separately from the arithmetic: hand insertion only, controlled press, temporary retention, repeated removal, no perceptible play, torque transmission, thermal cycling or corrosion exposure. The authorized engineering decision must connect that objective to a suitable completed specification.

> **NO GENERIC “BEST FIT”**
>
> A commonly used code or clearance may be unsuitable once the actual pin material, finish, force, temperature, lubrication, life and failure consequence are known.

07 / INTERFACE CONDITIONS

Account for effects that consume the margin

The smallest nominal clearance is not the only margin that matters.

Condition	Planning question	Potential consequence
Finish or coating	Is the feature final after finish? Which surfaces are masked, processed or measured?	Effective size can change; a prior machining result may not represent delivery.
Temperature	What are the machining, inspection and service temperatures? Are materials different?	Relative expansion can change an assembly condition.
Burrs and entry edge	What edge-break or burr condition is allowed at the mating entry?	A bore may measure in range yet damage or block the pin at insertion.
Contamination	Is debris, oil, plating residue or anodize sealing relevant?	Assembly force and repeatability may change without a nominal-size shift.
Wear and cycles	Is the location one-time, repeated, sliding or subject to vibration?	Initial assembly alone may not be the full functional test.

Do not add an assumed coating thickness or thermal correction to a released drawing without the product owner. Capture the final-state question, obtain process information where authorized, and analyze the actual stack. A supplier should identify a missing assumption rather than silently build it into the machining tolerance.

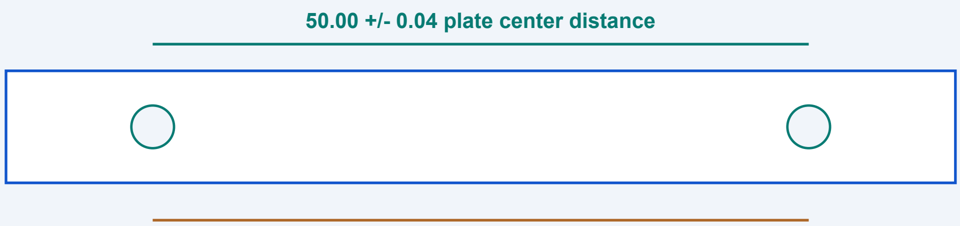
Use a finish-aware handoff

Name the sequence: machine, inspect before finish if required, finish, protect/mask, inspect final feature if required, clean, pack. Then identify which record proves each required condition. The sequence is part of the requirement when it affects a mating interface.

08 / STACK-UP

Budget a two-feature pattern before it surprises assembly

Pattern mismatch has a direction and a reference frame; a single plus/minus number rarely tells the full story.



One-dimensional extreme mismatch: 0.07 mm. Teaching calculation only.

A simplified LX-62 teaching calculation uses a 50.00 mm bore-center separation with plate limits of 50.00 +/- 0.04 mm and mating pin separation of 50.00 +/- 0.03 mm. The plate can be 49.96 to 50.04 mm; the pin pattern can be 49.97 to 50.03 mm. The largest one-dimensional extreme difference is 50.04 - 49.97 = 0.07 mm. The opposite extreme has the same magnitude.

Step	Original calculation
Plate separation range	50.00 +/- 0.04 = 49.96 to 50.04 mm.
Mating pin separation range	50.00 +/- 0.03 = 49.97 to 50.03 mm.
Worst one-dimensional separation mismatch	max(50.04 - 49.97, 50.03 - 49.96) = 0.07 mm.
What must still be analyzed	Bore clearance, position direction, datum constraints, angular error, form, entry, clamp flexibility and assembly method.

A TEACHING STACK IS NOT AN ASSEMBLY PROOF

The calculation intentionally reduces a spatial geometric condition to one distance. Do not use it to authorize an actual two-pin design. A functional analysis needs the actual mating geometry and controlled requirements.

09 / FIT INTENT

Decide whether clearance, transition or interference is intended

The design authority must define the assembly regime before manufacturing is asked to hold it.

Clearance means the simplified size relationship permits space between features at the stated extremes. Interference means the simplified size relationship overlaps at the stated extremes. A transition region may produce either outcome depending on actual sizes. These words describe a mathematical relationship; they do not by themselves state press force, retention, fretting risk, installation method or safe assembly sequence.

Intent statement	Missing information to resolve before release
“Pin should slide in by hand”	Maximum insertion force, chamfer, cleanliness, mating range, access, temperature and test method.
“Pin retains the part”	Load direction, service cycles, material strength, hole condition, insertion tool, removal expectation and authority.
“No movement at the interface”	Which motion, load, torque, temperature, surface state and how the condition is verified.
“Use a press fit”	Actual materials, wall thickness, local stress, geometry, lubrication, assembly force/displacement control and disposition for a failed press.

A live interference design can be sensitive to material condition and local geometry. Do not substitute a generic internet recommendation for a responsible analysis. If the drawing requests a code-system fit, ensure every participant uses the same applied standard and understands the controlled mating configuration.

SEPARATE DESIGN FROM PROCESS CAPABILITY

A feature can be functionally correct yet challenging for a chosen route, and a stable process can make the wrong functional requirement very consistently. Discuss both decisions explicitly.

10 / GD&T INTENT

Use geometric tolerancing to express the relationship

Geometric controls can make the functional relationship clearer when their datum references and verification are understood.

DATUMS →	ZONE →	METHOD →	REPORT
Reference	Allowed relationship	Simulate + measure	Retain evidence

A geometric control works only with its defined references, interpretation and verification plan.

A bore may need a size limit and a relationship to datum A, B and C. A position requirement can communicate a location zone relative to references; orientation and form requirements serve other distinct needs. The correct callout comes from the function, not from a desire to make an inspection report look sophisticated. Establish the datum system, the feature interpretation and the agreed standard before issuing a live specification.

Control purpose	Avoid this common shortcut
Location of a pin bore	Do not attempt to control a functional pattern only with separate X and Y coordinates unless that representation is deliberately intended.
Axis direction	Do not assume a diameter limit controls axis orientation.
Mating face condition	Do not assume a location callout makes a warped or rough seating face acceptable.
Pattern function	Do not apply a frame copied from another drawing when the mating datum sequence differs.

ISO 1101 provides the symbol language and ISO 5459 addresses datums and datum systems. Their full rules are not reproduced here. A clear drawing should also identify material state, modifiers if applicable, notes, general tolerances and any special inspection instructions through controlled documentation.

TEACH THE RECEIVER, THEN VERIFY THE INTERPRETATION

Before first production, review the feature with design, manufacturing and inspection using the same released revision. Capture questions and decisions; do not rely on spoken memory.

Sources: [03] ISO | [04] ISO

11 / LOCATION LOGIC

Make position useful at the mating condition

A feature-location result is only as useful as the references, zone definition and setup used to obtain it.

For a two-pin pattern, start with the actual assembly constraint. One locator may establish origin while a second constrains rotation; the mating design may intentionally allow freedom in one direction. The drawing should not accidentally demand zero freedom merely because two holes are nominally identical. Consider whether the mating part uses round and diamond pins, slots, compliant features or another strategy.

Review prompt	Reason
Which pin or feature locates first?	It determines the origin and how the second feature absorbs or constrains variation.
What motion must remain free?	A redundant constraint can make otherwise good parts fight during assembly.
Which surface seats on datum A?	A part that rocks or is clamped differently can give a misleading coordinate result.
How are multiple features evaluated?	A feature-by-feature check may miss a pattern or composite functional behavior.

Do not infer an inspection construction from the appearance of a CAD view. Record the alignment procedure, fixturing and report convention. If a functional gage is the contractual method, identify its controlled configuration and acceptance rule rather than trying to recreate it from an informal sketch.

12 / FORM, AXIS AND EDGES

Control the features that make a bore usable

A gauge reading at one depth is not automatically evidence about the full functional feature.

Feature condition	Why a diameter reading may be insufficient
Taper or lobing	A local bore measurement can be within size while another cross-section blocks or loosens the pin.
Axis direction	A pin may start correctly but bind or locate differently with depth.
Interrupted geometry	Slots, thin walls, cross holes and partial arcs can change what a size measurement represents.
Entrance damage	Burrs, sharp edges and raised material can alter assembly without changing the reported diameter.
Surface condition	Texture, plating, anodize or debris may be functionally relevant depending on the interface.

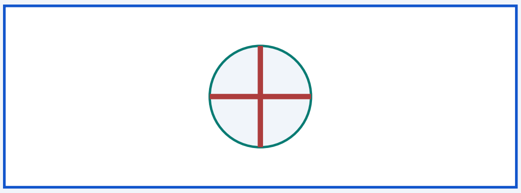
The right method depends on the actual feature. A pin gage, air gage, bore gage, CMM, optical method or functional gage can each be useful within a defined task. Name the instrument only after deciding what property is being evaluated, at what locations, relative to which datums, in what delivered condition and using what decision rule.

> **A METHOD TITLE IS NOT A METHOD INSTRUCTION**
>
> “Inspect on CMM” does not identify probe strategy, alignment, measurement points, filtering, fixturing, report output, uncertainty context or who may release a borderline result.

13 / FINISH AND EDGES

Treat surface and edge notes as interface controls

Requirements that look secondary can control whether a carefully dimensioned assembly actually goes together.



entry edge

FINAL-STATE QUESTIONS

Burr / edge break
Finish sequence
Masking / coating
Cleanliness and packing

An edge-break instruction can protect a mating pin and make assembly repeatable. A surface requirement can affect sealing, sliding, paint adhesion, contact and appearance. A finishing route can alter a dimension. These effects should be attached to a functional reason, a final-state definition and an inspection path rather than hidden in a generic note that different readers interpret differently.

Question to put on the review list	Practical consequence
Where is an edge condition critical?	Identify bore entry, sealing land, thread start, hand-contact edge or datum contact separately.
Does finish occur after critical machining?	Define whether final inspection occurs before or after finish and which surface may change.
Is a roughness value functional or cosmetic?	Tie it to the contact, sealing, sliding or appearance purpose and specified method.
Are exceptions visible?	Masks, plugged holes, protected faces and no-finish areas need controlled representation.

Avoid inventing blanket “deburr all edges” limits if a controlled drawing already defines an edge system. Instead, resolve conflicting notes and make the significant interface edges visible to the route, inspector and final packer.

14 / BUDGETING

Build a tolerance budget that is explainable

A budget assigns the available functional margin to real contributors and records what is assumed.

Start with the function’s allowable motion, alignment or gap. List contributors by physical mechanism: mating size ranges, feature location, form, datum seating, finish, thermal state, fixture/compliance effects and measurement/decision treatment. Put each item in a common direction or model only when the representation is valid. Flag contributors that are correlated, directional or not credibly reduced to a simple linear sum.

Budget column	Use it to expose
Functional limit	The measurable assembly condition that must be preserved.
Contributor and direction	Which part, feature or process can move the condition, and in which direction.
Range or model basis	Released limit, actual certificate range, measured history, simulation or open assumption.
Allocation owner	Drawing owner, mating-part owner, finisher, inspection or assembly authority.
Verification and residual	How the contributor is checked and what remains unverified.

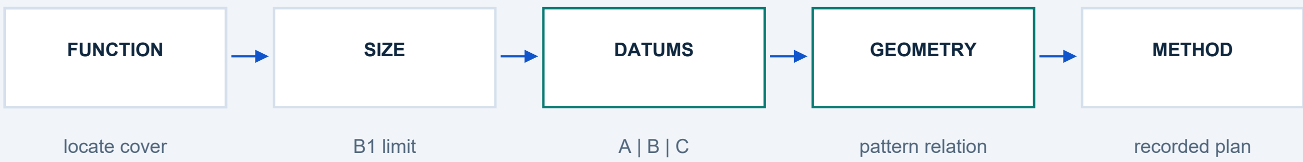
DO NOT HIDE UNCERTAINTY IN A “SAFETY FACTOR”

A reserve can be useful when it is explicitly justified. It becomes dangerous when it hides missing mating data, unmodeled coating, a vague datum strategy or an unagreed decision rule.

15 / DRAWING REVIEW

Write a drawing that survives handoff

A supplier, inspector and customer should be able to identify the same requirement without reconstructing a private mental model.



A controlled handoff connects function, requirement, route and evidence in the same revision.

Release a controlled package: drawing or model as agreed, revision identifier, units, material and state, finish and final condition, feature requirements, datum scheme, special notes, inspection deliverables and authorized deviations. Link any external specification by its complete identifier and applicable edition or contract reference. Remove duplicate dimensions or notes that could conflict after a revision.

Pre-release check	Question
Completeness	Can the feature be made and inspected without guessing a material state, extent, unit, reference or final condition?
Consistency	Do model, drawing, note, RFQ, inspection plan and customer-supplied mating data identify the same revision?
Function	Does each critical control correspond to a known failure mode or assembly need?
Verification	Is the intended method, report and decision authority defined for each CTQ?
Change control	Will an altered coating, fixture, program, gage or mating part trigger review?

A review checklist is not an approval by itself. Record who owns each open question and what evidence resolves it. Never turn an unresolved technical question into a production assumption just because a schedule is tight.

16 / INSPECTION PLANNING

Classify features so the inspection plan has a purpose

Inspection effort should follow function, risk, process knowledge and the agreed contract - not a habit of measuring everything the same way.

Create a feature register for the released revision. For each feature, identify the characteristic, requirement reference, functional reason, classification, delivered state, measurement stage, method, fixture/datum references, record, decision rule, sampling or frequency, owner and reaction plan. A compact plan that answers these questions is more useful than a long generic inspection report.

Feature class example	Planning response
CTQ or interface feature	Define method, setup, evidence, decision authority and response before production.
Process-control feature	Choose a stage and frequency that can prevent a known drift or setup error.
Documentation feature	Verify required material, finish, certificate, marking or traceability against the order.
Visual/edge feature	Use clear acceptance criteria, lighting/access context if relevant and record approach.

CLASSIFICATION IS NOT A SUBSTITUTE FOR AN ACCEPTANCE REQUIREMENT

Calling a feature “critical” does not tell an operator the limit, method or disposition. The released requirement must still make the decision possible.

17 / METHOD SELECTION

Select a method that sees the required property

Measurement capability comes from the complete task: feature, instrument, setup, operator, environment, software and decision.

PIN / BORE GAGE	CMM	FUNCTIONAL GAGE	VISUAL / SURFACE
size	datum-based geometry	assembly condition	edge or finish

Choose the method only after naming the property, references, final state and decision.

A simple direct gage can be excellent for a clearly defined diameter and poor for a datum-related pattern. A CMM can assess complex geometry and still be unsuitable if fixturing, probing, filtering or alignment do not represent the requirement. A functional gage can mimic assembly and still need a controlled configuration, maintenance and decision rule. Start with the property to be judged, then select and validate the method.

Method-planning question	Record it in the plan
What property and locations are evaluated?	Size, form, axis, position, surface or assembly behavior; include feature extent.
What establishes the references?	Fixture, contacts, alignment, datum simulation and clamp condition.
What is the data output?	Raw values, pass/fail, report characteristic ID, program/version and attachment.
What can invalidate a reading?	Temperature, stylus access, gage wear, dirt, operator technique or software change.

NIST notes that a CMM calibration and a specific CMM measurement task are different issues. Preserve the method version and setup information needed to interpret a result later; a report with only a green check mark may not support a dispute or change review.

Sources: [08] NIST | [12] NIST

18 / MEASUREMENT SYSTEM

Control the measurement setup, not just the instrument

A traceable instrument is necessary but does not eliminate setup, sampling and human variation.

Setup element	Why it belongs in an instruction
Part condition	Temperature, cleanliness, stabilization, finish state and handling affect what is being measured.
Fixturing	Support and restraint can change datum contact, deform thin parts or hide a functional condition.
Instrument configuration	Range, contact force, probe, stylus, calibration status, program and reference artifact affect the task.
Operator sequence	Zeroing, insertion depth, rotation, reading, repeat measurement and recording must be consistent.
Data integrity	Unit ID, characteristic ID, method revision, timestamp and exception record make the result traceable.

Metrological traceability is a property of the stated result supported by an unbroken documented calibration chain and uncertainty information. It is not a synonym for “the gage has a sticker.” If measurement uncertainty, resolution or method variation could change a decision, escalate that issue before using the result as a release basis.

MATCH THE METHOD TO THE DELIVERED PART

A before-finish result, a warm part on the machine, or a sample measured under a different datum strategy can be valuable process information but may not be final acceptance evidence.

Sources: [08] NIST | [10] NIST/SEMATECH | [12] NIST

19 / MSA

Plan a gauge study that resembles the real decision

A study is useful when its parts, operators, setup and process conditions represent the task it is meant to support.

Before launching a repeatability and reproducibility study, define the characteristic, part population, expected range, fixture, gage, instruction, operator population, environmental controls and analysis plan. Include variation relevant to the decision, especially parts near the specification boundary if that is where risk matters. Do not reuse a convenient historic study after a new fixture, probe, software, operator method or product geometry changes the measurement task.

Study review prompt	Reason
Are the parts representative?	A set with little part-to-part variation may not reveal how the method behaves across the working range.
Are operators and setups realistic?	A single expert under ideal conditions can overstate routine inspection performance.
Is the instruction frozen?	A changing method turns one study into several incompatible experiments.
What decision will use the result?	Tie the study to setup approval, process monitoring, acceptance or troubleshooting - not a generic score.

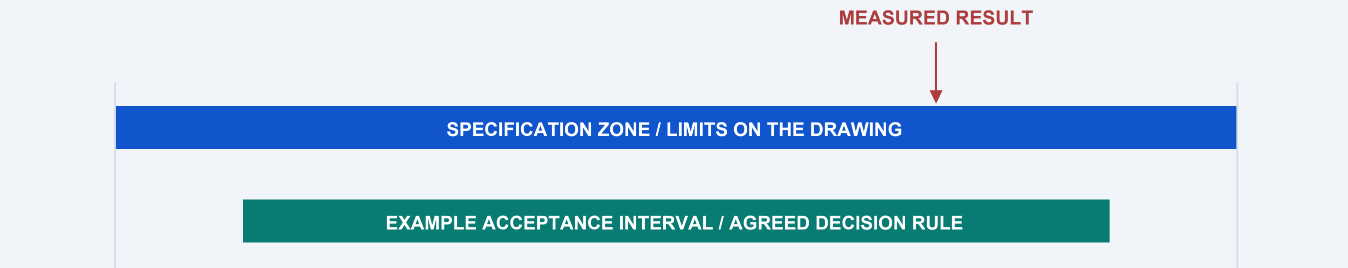
NIST separates repeatability, reproducibility, stability, bias and resolution among measurement-process concerns. Select the analysis and acceptance logic required by your organization or customer; this guide does not impose a percentage threshold or certify a gage study.

Sources: [10] NIST/SEMATECH | [11] NIST/SEMATECH

20 / CONFORMITY

Agree the decision rule before a borderline result

A measured value near a limit is not self-interpreting when uncertainty must be considered.



Any acceptance boundary or guard band must be agreed before the result is decided.

The specification zone is the range allowed by the requirement. A decision rule states how the measurement result and its uncertainty are considered when declaring conformance or nonconformance. The purchaser, drawing owner, laboratory and supplier should know the applicable rule before inspection begins, especially where a feature is close to a boundary. Record the rule reference in the inspection plan and report where required.

Decision question	What to make explicit
What is the requirement?	Characteristic, limits, units, final state and controlled revision.
What was measured?	Result, method, setup, date, instrument and raw or retained evidence.
How is uncertainty handled?	Contractual or organizational decision rule, guard band if any and authority for exceptions.
Who decides an exception?	Named customer/design/quality authority; no implied supplier waiver.

DO NOT SILENTLY MOVE THE LIMITS

A guard band or other rule can change acceptance risk. It must be agreed and recorded, not applied informally after a result is seen. This guide does not prescribe one.

Sources: [05] ISO | [09] NIST

21 / DATA PLAN

Record data so it can answer the next question

A usable record connects a result to the part, requirement, method, condition and decision that produced it.

For a CTQ, record more than a pass/fail flag when the contract and method require values. Include part or lot identity, characteristic ID, drawing revision, nominal and limits, actual result and units, method or program version, datum/fixture reference, gage identification, operator or system, date, disposition status and exception reference. Preserve the evidence appropriate to the risk and traceability requirement.

Data use case	Minimum linkage
First-off review	Released revision, setup, program/fixture, feature results, reviewer and release decision.
In-process control	Machine/setup state, time/order, method, result, trend/reaction action and affected population.
Final report	Delivered state, traceable IDs, required characteristics, method statement and decision rule reference if applicable.
Customer question	Original raw record, report version, certificate/finish linkage and authorized response.

Keep personal and proprietary data to the approved scope. A complete technical record is not permission to share customer models, program code or internal analysis beyond the agreed channel.

22 / COVERAGE

Choose sampling as a controlled risk decision

Sample size, frequency and 100 percent inspection are process choices with assumptions - not labels that automatically guarantee quality.

Control choice	Use only after defining
First-off or setup verification	What setup changes trigger it, which features are checked, who releases the start and what happens when it fails.
Periodic sampling	Lot/process definition, frequency, randomization or sequence, reaction plan and population boundary.
100 percent inspection	Method capability, throughput, record linkage, reviewer controls and handling of nonconforming units.
Functional audit	Representative assembly, fixture, environmental condition, pass criteria and authority for a failure.

More measurements do not repair an unclear requirement or unreliable method. Conversely, a stable, validated process may support a different control plan than an unfamiliar launch. Document the rationale, make changes visible, and do not use the word “inspection” as a substitute for prevention or process understanding.

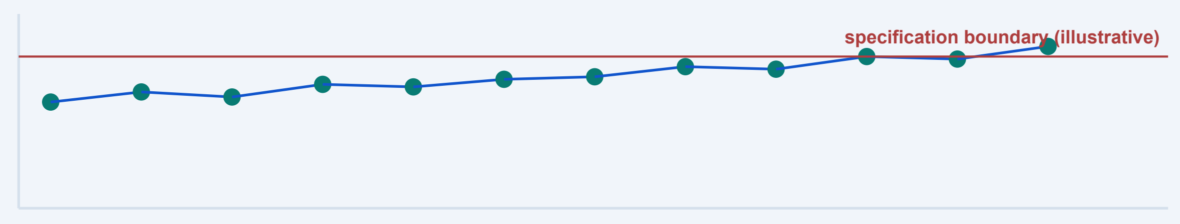
BOUND THE POPULATION

When a control detects a problem, identify the last known acceptable condition, the possible affected range, the evidence supporting that range and the authority that approves the resulting action.

23 / MONITORING

Use trends without pretending a small sample proves capability

Data becomes useful when it is linked to a stable process definition and a response plan.



Illustrative trend: investigate causes; do not claim capability from this sketch.

A sequence of readings can reveal a tool change, thermal drift, offset adjustment, fixture issue or data-entry error. Plot the characteristic in its production order, annotate changes and investigate special patterns using the local process knowledge. Keep the requirement limits distinct from any statistical monitoring limits; they answer different questions and should not be confused on a report.

Trend review	Disciplined response
Reading approaches a specification boundary	Check method, setup and process cause; do not wait for an out-of-limit result if the response plan calls for action.
Step shift after a change	Verify tool, offset, material batch, fixture, program and measurement-condition changes.
Scatter increases	Review method stability, tool condition, workholding, material and environmental contributors.
Data is sparse or mixed	Do not calculate a persuasive capability number; first define a comparable process population.

Trend plots in this guide are illustrative only. They do not establish process capability, a defect rate or a release criterion. Use the statistical procedures required by the actual customer, quality system and controlled process.

Sources: [13] NIST/SEMATECH

25 / REVIEW GATE

Run a cross-functional tolerance review

A good review exposes assumptions before a buyer, programmer or inspector has to make them under schedule pressure.

Bring design, manufacturing, quality and the relevant mating-part or customer authority together around the released package. Read critical interfaces feature by feature: function, failure mode, requirement, datum references, material and final state, process route, method, decision rule, record and change triggers. Capture unanswered questions as controlled actions with owners and due dates.

Role	Useful contribution
Design / product authority	Defines function, assembly conditions, acceptance intent and authority for technical changes.
Manufacturing	Identifies route, workholding, tool access, process sequence, finish constraints and controllability concerns.
Quality / metrology	Tests whether method, fixturing, data and decision rule can support the intended evidence.
Buyer / program owner	Aligns revision, commercial scope, lead time, certificates, change communication and customer approvals.

The meeting is a decision record, not an informal promise. Publish the revision reviewed, decisions made, open issues, permitted work and release restrictions. A new coating source, mating revision, fixture, gage program or process step may reopen the relevant interface analysis.

26 / WORKED PLAN

Build the LX-62 feature plan

The case is converted into an inspection-plan excerpt without claiming it is a universal template.

Plan the complete measurement decision before first-off production.

For LX-62, B1 is recorded as an interface feature after the agreed final process state. The plan must name the bore requirement reference, the actual customer pin range used in the interface analysis, the datum strategy for the pattern, the selected bore and location methods, raw-data requirement, decision rule reference, sampling/coverage rationale and reaction plan. “Inspect B1” is not enough.

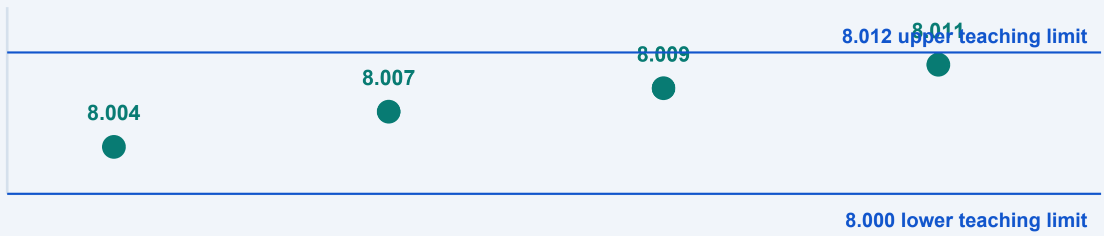
Plan field	LX-62 illustrative entry
Characteristic	B1 final bore size and separately defined location relationship.
Requirement basis	Released drawing revision and linked interface record; fictional numerical values in this guide are not the live baseline.
Method	Approved bore method for the specified feature extent; controlled fixture/alignment for location.
Decision	Agreed acceptance rule and escalation path for borderline results.
Record / reaction	Part ID, result, method version, gage ID and controlled hold/escalation when required.

If a customer changes the pin certificate range, finish sequence or cover geometry, do not merely edit a spreadsheet cell. Revisit the mating condition and confirm whether size, location, method or assembly evidence must change.

27 / WORKED MEASUREMENTS

Read LX-62 results without overclaiming

Individual readings are observations; their interpretation depends on the controlled method and acceptance context.



Four readings are observations, not a capability claim.

Assume four fictional B1 size readings after the agreed final state: 8.004, 8.007, 8.009 and 8.011 mm. They lie inside the teaching limits of 8.000 to 8.012 mm. For the customer pin range of 7.994 to 7.998 mm, the smallest size-only clearance implied by the four readings occurs at B1 8.004 with pin 7.998: 0.006 mm. The largest shown combination is 8.011 - 7.994 = 0.017 mm.

What can be said in this teaching example	What cannot be said
The four stated readings are numerically inside the fictional size limits.	That every bore on a lot is acceptable or that the route is capable.
The shown size-only clearance range is 0.006 to 0.017 mm for the stated combinations.	That the cover will always assemble; geometry, finish, temperature and method effects are excluded.
Results should be linked to the method and final condition.	That a number from an unknown setup proves conformity.

DO NOT CONVERT FOUR READINGS INTO A CAPABILITY CLAIM

The values are deliberately limited to show arithmetic and record discipline. A real assessment needs a defined, representative process and method.

28 / WORKED STACK REVIEW

Check the LX-62 pattern as a separate relationship

A size result and a pattern result should remain separate until the functional model justifies combining them.

The earlier one-dimensional teaching stack gave a 0.07 mm extreme separation mismatch from the two specified center-distance ranges. That is not a position evaluation, a true-position result or a functional-gage result. It only shows why a designer cannot decide the second-pin behavior from B1 diameter alone. Actual two-dimensional location, datum seating, hole clearance, orientation and pin design must be addressed in the released interface definition.

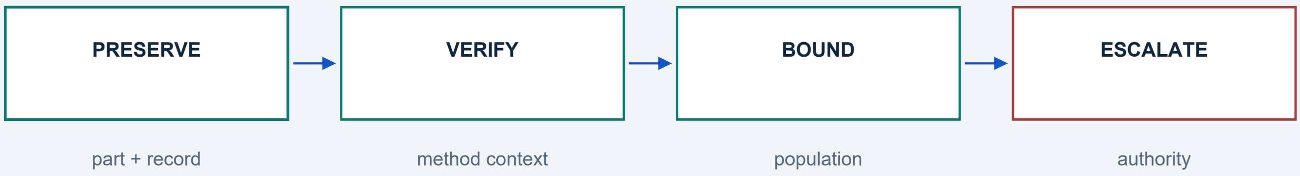
Review item	LX-62 evidence needed before release
Primary locator	Which bore/pin/reference establishes the assembly origin and how it is simulated.
Secondary locator	What degree of freedom it constrains, what clearance/slot strategy exists and why.
Pattern requirement	Controlled location callout or dimensions, datum system and applicable standard interpretation.
Inspection	CMM/fixture/functional-gage instruction, program/version, raw evidence and decision rule.
Assembly confirmation	Defined cover, pins, condition, force/feel criterion if applicable and decision authority.

This separation protects the team from a common error: declaring an assembly “good” because each isolated dimension passes. Interfaces are relationships, and relationships need a complete model.

29 / NONCONFORMING OR BORDERLINE RESULT

Use a disciplined reaction when a result is unclear

Do not let a technician, buyer or supplier carry an unagreed engineering decision alone.



A remeasurement or informal email does not move a limit or authorize a disposition.

When a result is out of limit, near a boundary under the applicable decision rule, or generated by a questionable method, preserve the part and evidence, identify the controlled requirement and measurement context, hold the defined population if required, and escalate through the agreed authority. Do not remeasure until a desired number appears, edit historical values, substitute a different method without disclosure or ship based on an informal verbal waiver.

First response	Purpose
Record the actual condition	Protects traceability of unit, requirement, method, result and time.
Verify the method appropriately	Distinguishes a possible measurement issue from a product decision without overwriting original evidence.
Bound the population	Connects potential exposure to lot, setup, route, change point and release status.
Obtain authorized disposition	Separates technical assessment, customer approval, rework authority and commercial communication.

A REPEAT MEASUREMENT IS NOT A DISPOSITION

A confirmation method can be necessary. It does not erase the original result, move the acceptance limit or authorize use-as-is.

30 / CHANGE MANAGEMENT

Define change triggers at the interface

A new version can be safe, risky or simply unknown; the interface review makes the distinction visible.

List changes that can affect the tolerance plan: mating-part revision, material or heat-treatment state, coating source or sequence, finish masking, fixture, machine, program, tool strategy, gage, CMM program, datum setup, inspector instruction, sampling plan and decision rule. Tie each to an assessment and approval route. A document-control system is useful only when it reaches the people and records that depend on the change.

Change	Re-review question
New coating or sealing route	What is the final effective interface state and how is it verified?
New pin supplier/range	Does the updated mating range preserve the functional clearance and pattern analysis?
New fixture or CMM program	Does datum simulation and measurement uncertainty remain appropriate to the requirement?
New machining route	Are capability, process controls, first-off and data records adequate for the released limits?
New customer drawing revision	Which requirements, reports, programs and stock are superseded or require re-verification?

A change assessment may conclude no impact, but it should state the evidence and scope. Do not infer that a familiar process name makes an interface unchanged.

31 / HANDOFF

Release with an evidence package, not just a PDF report

The recipient needs enough controlled information to understand what was delivered and what remains conditional.

For a defined order, the handoff package may include the released drawing/model revision, material and finish records as required, lot/part traceability, inspection report with characteristic linkage, method/revision information, certificate scope, approved deviation or concession records where applicable, and packing/identification requirements. The exact package follows the contract and product requirements; do not add or omit controlled records by habit.

Recipient question	Package element
What part state was delivered?	Part/lot identity, revision, material/finish state and any required certificates.
Which features were verified?	Inspection plan/report linkage, results, method and any stated sampling or coverage.
How was a decision made?	Applicable requirement, decision-rule reference where required and authorized exception records.
What changed or remains open?	Controlled deviation/change references, known limitations, owner and next action.

AVOID MARKETING CLAIMS IN QUALITY RECORDS

A certificate, report or download should state its actual scope. It should not imply a product certification, universal fit guarantee or independent approval that has not been provided.

32 / PRACTICAL CHECKLIST

Use the release checklist before the first controlled run

This page turns the method into a final pre-production conversation.

Check	Question to close
Function	Is the interface behavior, load, environment and assembly condition known or formally open?
Mating stack	Are real mating ranges, finish states, temperature and directional contributors identified?
Specification	Are size, geometry, datums, material/finish state, notes and revision consistent?
Inspection	Does each CTQ have a method, setup, record, decision rule, coverage and reaction plan?
Measurement system	Is the task method controlled and supported by appropriate calibration, instruction and study evidence?
Change control	Are triggers for new parts, finish, tools, fixtures, gages and revisions visible?
Authority	Are technical decisions, dispositions and customer approvals assigned to the right people?

If an answer is unknown, write it as an open item with an owner and due date. The useful output is not a perfect checklist score; it is a controlled path that prevents silent assumptions from becoming manufactured variation.

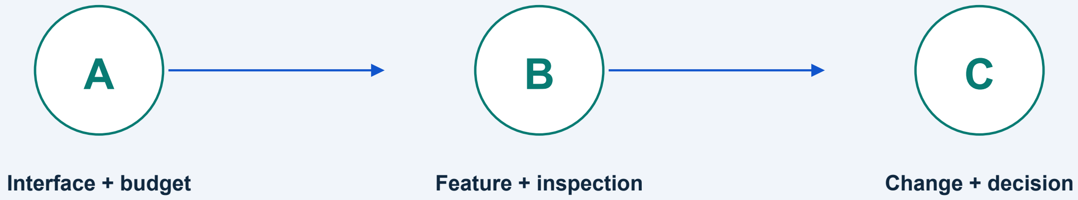
A CONCISE REQUEST TO A MACHINING PARTNER

Share the current drawing/model revision, mating requirements, material and final finish, quantity, required evidence, intended assembly behavior, deadline and unresolved questions. A good quotation discussion begins where the engineering decision is still open.

33 / SUMMARY

Keep the planning pack usable

The three worksheets that follow keep the requirement, measurement and change decisions visible.



Use the next worksheets to surface assumptions before they become variation.

Use Appendix A before a drawing or RFQ release to describe the interface and tolerance budget. Use Appendix B to create a feature-level inspection plan that a machinist, inspector and customer can read consistently. Use Appendix C when a process, mating part, finish or measurement change may affect the released interface. Attach controlled drawings, reports and approvals rather than forcing detailed evidence into a small form field.

Worksheet	Best time to use it
A. Interface and tolerance plan	Before selecting a code, issuing a drawing or accepting a supplier assumption.
B. Feature and inspection plan	Before first-off, process release or a customer-required report.
C. Change and decision review	Before changing a mating condition, route, finish, fixture, gage, program or acceptance logic.

The worksheets do not calculate fits, sign approvals, transmit data or override controlled documents. Save copies only through your approved information-management process. The final engineering authority remains responsible for the live specification and product decision.

APPENDIX A / REUSABLE WORKSHEET

Your interface and tolerance plan

Write the functional condition before selecting a fit code, a limit or a measurement method.

Part / revision / intended function

Mating parts / ranges / final condition

Assembly condition / load / environment

Failure modes / unacceptable behavior

Feature / datum / requirement reference

Contributors / budget basis / assumptions

Finish / temperature / edge conditions

Authority / evidence / open decisions

Functional acceptance statement, linked drawing records and unresolved engineering questions

- [ ] The actual mating stack and final state are identified or explicitly open.
- [ ] No generic fit code or teaching calculation has been treated as a release decision.

Save and reopen in a form-capable PDF reader. Fields do not calculate, select a fit, authorize a product decision, sign approval or transmit data. Attach detailed records separately.

APPENDIX B / REUSABLE WORKSHEET

Your feature and inspection plan

Use one worksheet for a critical feature or linked feature set. Attach detailed reports by reference.

Part / revision / characteristic ID

Function / classification / delivered state

Requirement / datum / feature extent

Method / fixture / program or gage ID

Record values / coverage / frequency

Decision-rule reference / release authority

Reaction plan / population boundary

Owner / method revision / review date

Measurement-system evidence, uncertainty context, exceptions and attachment index

- [ ] The method evaluates the required property using the stated references and condition.
- [ ] Borderline, nonconforming and change decisions have an assigned authority.

Save and reopen in a form-capable PDF reader. Fields do not calculate, select a fit, authorize a product decision, sign approval or transmit data. Attach detailed records separately.

APPENDIX C / REUSABLE WORKSHEET

Your change and decision review

Use before a change to a mating part, finish, route, fixture, gage, program or acceptance logic.

Part family / revision / change ID

Change description / effective date

Affected interface / feature / function

Mating ranges / finish / final-state impact

Requirement / method / datum impact

Evidence required / trial / review plan

Population / customer / records impacted

Decision authority / status / next action

Residual risks, linked approvals, disposition limits and follow-up verification

- [ ] The change is evaluated against the released interface, not only a nominal dimension.
- [ ] No production, release or customer claim is authorized by this worksheet alone.

Save and reopen in a form-capable PDF reader. Fields do not calculate, select a fit, authorize a product decision, sign approval or transmit data. Attach detailed records separately.

REFERENCE REGISTER / 1

Primary sources and their scope

Public sources checked 21 September 2026. Linked titles open the source; case facts, calculations, diagrams and worksheets are original.

[01] ISO

ISO 286-1:2010 - ISO code system for tolerances on linear sizes

Official catalogue scope: ISO 286-1 establishes the ISO code system for tolerances on linear sizes and related terminology, including basic-hole and basic-shaft concepts. It is not reproduced here; use the applicable licensed edition and project requirements.

[02] ISO

ISO 286-2:2010 - Tables of standard tolerance classes and limit deviations

Official catalogue scope: ISO 286-2 provides values for common tolerance classes and limit deviations for holes and shafts. This guide deliberately does not reproduce tables or select a fit from a code alone.

[03] ISO

ISO 5459:2024 - Geometrical product specifications: datums and datum systems

Official catalogue record for ISO 5459:2024, published in October 2024. It addresses datums and datum systems used in geometrical specification and verification.

[04] ISO

ISO 1101:2017 - Geometrical tolerancing

Official catalogue scope: ISO 1101 defines the symbol language and rules for geometrical specification. The current, contractually applicable drawing and standard control a live part.

[05] ISO

ISO 14253-1:2017 - Decision rules for proving conformance or nonconformance

Public scope for decision rules used in measurement-based conformity assessment. It distinguishes specification zones, acceptance and rejection risks. It does not make this guide a default rule for a transaction.

[06] ISO

ISO 14405-1:2025 - Linear sizes

Official catalogue record: ISO 14405-1:2025 establishes requirements for the indication of linear sizes. It does not itself translate a function into a size requirement.

[07] ISO

ISO 14405-2:2018 - Dimensions other than linear sizes or angles

Official scope notes that dimensions can otherwise be ambiguous when they control properties other than a linear size or angle. Use an unambiguous, agreed specification for the intended function.

Catalogue records establish public scope and edition context, not access to licensed clauses or permission to reproduce tables. Apply the full agreed standard and product requirements. The LX-62 case is not a validated design, an accredited test or independent technical approval.

REFERENCE REGISTER / 2

Primary sources and their scope

Public sources checked 21 September 2026. Linked titles open the source; case facts, calculations, diagrams and worksheets are original.

[08] NIST

Metrological Traceability: Frequently Asked Questions and NIST policy

NIST explains traceability as a property of a measurement result supported by an unbroken documented calibration chain with stated uncertainty. A calibration label alone does not show a method is fit for a particular feature.

[09] NIST

Decision Rule

NIST glossary: a decision rule states how measurement uncertainty is accounted for when making a conformity statement. Parties should identify the applicable rule before borderline results are decided.

[10] NIST/SEMATECH

Engineering Statistics Handbook: Measurement Process Characterization

NIST overview of repeatability, reproducibility, stability, calibration and uncertainty in a measurement process. A study must represent the actual measurement task.

[11] NIST/SEMATECH

Engineering Statistics Handbook: Gauge R&R studies

NIST explains gauge-study considerations including parts, operators, gauges, configurations, repeatability and reproducibility. A past study may not represent a changed method or workpiece.

[12] NIST

Traceability, calibration and measurement uncertainty for CMMs

NIST notes that CMM calibration and the actual measurement task are different issues. Part geometry, setup and conditions matter to task-specific uncertainty.

[13] NIST/SEMATECH

Engineering Statistics Handbook: Assessing Process Capability

NIST describes comparing process output with specification limits when assessing capability. Small illustrative samples in this guide are not a capability study or a process-rate claim.

[14] ILAC / IAF / ISO

Joint communique on ISO/IEC 17025 management-system requirements

Public communique explains that ISO/IEC 17025 addresses technical competence and management-system requirements for valid test and calibration results. Review the laboratory scope and method suitability for a live job.

Sources support the principles identified in this guide; they do not endorse Vetcnc or validate the fictional case. Recheck current source status, laboratory scope, contractual decision rule, regulatory requirements and product-specific engineering responsibilities before a live release. No certification or independent professional approval is implied.

vetcnc
CNC MANUFACTURING

A BETTER TOLERANCE DISCUSSION STARTS WITH THE INTERFACE

Bring the function.
Bring the mating facts.

Share the current drawing revision, mating condition, material and finish, quantity, intended assembly behavior and required evidence. Keep any open engineering decision visible before machining starts.

01 **DEFINE**

The interface, function, final state and variation that can change it.

02 **CONTROL**

The drawing, datum strategy, route, method and decision rule.

03 **VERIFY**

The measured evidence, change review and authorized handoff.

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