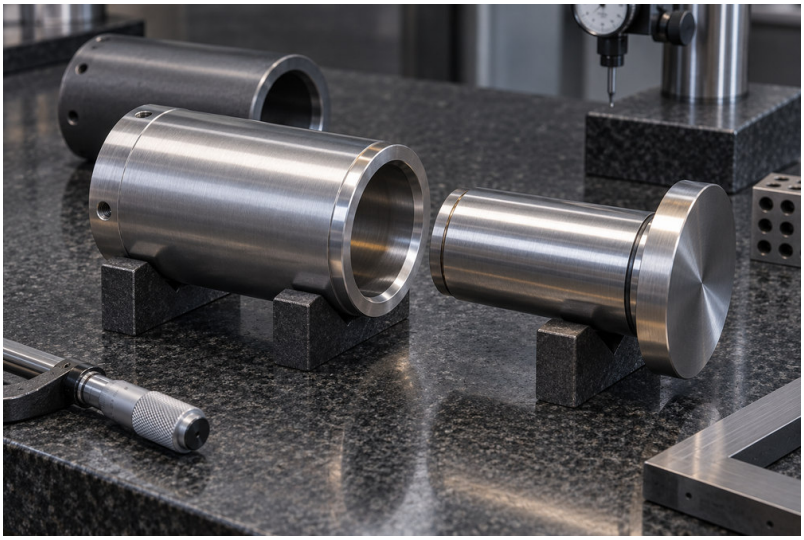
Why an Identical Replacement Can Bind in the Cold

A matching measurement is a starting point



The mating pair is the unit of comparison when a housing material changes.

A removable camera cartridge slides smoothly into its housing in the workshop. A replacement housing has the same bore diameter and bolt pattern, so the first assembly looks successful. Yet changing the housing material can change that fit in the cold. The drawing may look familiar while the behaviour has changed.

This is a useful way to examine subsystem ownership. The practical benefit is the ability to investigate and control the whole change: material, geometry, mating part, operating conditions and verification. Local manufacture can shorten that conversation when the same organisation controls those decisions. Its location alone does not establish technical authority or compatibility.

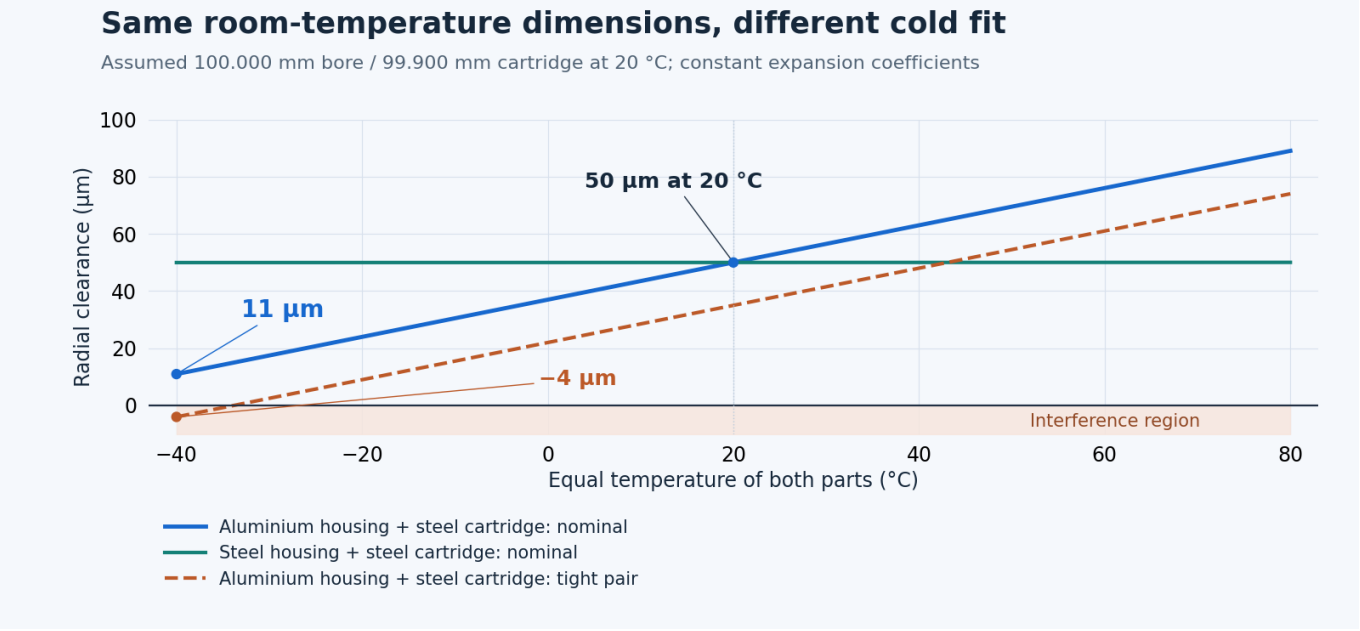
Precision dimensions need a reference temperature. NIST's account of the 20 °C reference explains the underlying problem: mating parts made from different materials grow by different amounts. A valid dimensional inspection at the reference condition is valuable, but it is not an operating-temperature fit test.

Imagine a steel cartridge inside a steel housing. The design team proposes an aluminium housing while retaining the original bore dimension. The calculation on the next page asks what that change does to radial clearance: the space between the two surfaces on one side. It deliberately leaves seals and interference stresses out so the first effect remains clear.

Inventra S³ describes mechanical design, thermal analysis, manufacturing and dimensional inspection on its engineering page. For a proposed change, connect those capabilities to this specific question: who can change the mating geometry, update the analysis and release the resulting configuration? A machining capability becomes useful evidence when it is connected to the actual requirement.

The replacement must preserve the required behaviour, not only the nominal dimensions.

The cold fit can use up most of the margin



Assumed geometry: different materials change the nominal fit; the permitted tight pair reaches interference.

Use an assumed bore diameter of 100.000 mm and cartridge diameter of 99.900 mm, both at 20 °C. Their diametral clearance is 0.100 mm; the radial clearance is half that, 0.050 mm or 50 micrometres. One micrometre is one thousandth of a millimetre.

OpenStax gives the linear approximation $\Delta D = \alpha D \Delta T$ and representative expansion coefficients of 25×10^{-6} per °C for aluminium and 12×10^{-6} per °C for iron or steel. These are teaching values, not specifications for a selected alloy. A real design needs properties appropriate to its exact materials and temperature range.

Now cool both parts uniformly from 20 °C to -40 °C, a change of -60 °C. The aluminium bore becomes 99.850 mm. The steel cartridge becomes 99.828072 mm. Subtracting and dividing by two leaves 0.010964 mm radial clearance: about 11 micrometres. Roughly 78% of the original 50-micrometre clearance has disappeared.

For comparison, if both parts use the assumed steel coefficient, the cold radial clearance remains about 49.964 micrometres. Equal fractional contraction nearly preserves this small fit allowance. With the aluminium housing, heating both parts to 80 °C instead increases the clearance to about 89 micrometres.

The plot is a first-order calculation with constant coefficients, free expansion and equal part temperatures. It establishes a sensitivity to the change; it does not predict insertion force or approve a service temperature. We still need to account for manufacturing limits and the physical conditions that the simple model omits.

A small difference in material expansion can be large compared with the available clearance.

The tightest pair can reverse the result

Check the part temperatures as well as the dimensions before assessing service fit.

Nominal clearance does not mean every permitted pair stays clear. Assume a manufacturing tolerance of ±0.015 mm on each diameter at 20 °C. The tightest pair combines the smallest bore and largest cartridge.

Bore / cartridge at 20 °C	Radial clearance at 20 °C	Radial clearance at -40 °C
Aluminium / steel: nominal	50 µm	11 µm
Aluminium / steel: tight pair	35 µm	-4 µm
Steel / steel: nominal	50 µm	50 µm

The 99.985 mm bore and 99.915 mm cartridge give about -4 micrometres at -40 °C. Negative clearance means the freely contracting surfaces would overlap. Contact and deformation must then replace the free-expansion assumption: possible binding, with no force calculated.

These tolerances are dimensional limits, not standard deviations. Statistical root-sum-square needs evidence about the production distributions and answers a different question. Here we examine the permitted extreme pair.

A cartridge from a warm store may be hotter than its outdoor housing, invalidating the equal-temperature assumption. Measure both parts, allow for gradients and calculate using their separate temperatures. Also assess surface finish, coatings, roundness and assembly restraint; diameter alone is insufficient.

Evaluate the mating pair at the adverse dimensional and thermal conditions.

Release the change with the evidence it alters

The clearance example identifies a specific dependency: housing material changes thermal movement; thermal movement changes fit; fit can change removal, insertion and alignment. Follow that chain before deciding what earlier evidence remains useful. The part's purchase price or share of local content does not measure the importance of this dependency.

The original room-temperature inspection method may remain useful for checking the new bore. Its result must still be recorded for the new part. The earlier steel-to-steel cold-fit calculation does not establish the aluminium-to-steel fit. A previous software interface test may remain applicable if the mechanical change has no effect on the tested interface; document that reasoning instead of discarding or reusing every report together.

NASA's configuration-management guidance distinguishes changes that affect interchangeability and external interfaces from changes that do not. It also connects the released product with its current and historical records. This is a useful discipline for a replacement: the approved drawing, material definition and compatibility information must describe the unit the service team actually receives.

For this example, the review could produce three linked outputs: a revised fit assessment across the required temperatures and tolerances; assembly evidence for the selected mating parts; and a released service instruction identifying compatible housings and cartridges. If the proposed geometry cannot keep the required clearance, the design decision comes before the release: revise the fit, select a different material, or change the requirement through an agreed process.

Keep the prototype decision separate from the supported option. Identify which delivered units may use the replacement, which spares remain compatible and which evidence applies. That is the practical value of controlling a subsystem design: a small part change can be developed into a complete, traceable engineering decision.

A supported replacement links the changed part, the compatible assembly and the revised evidence.

Sources and further reading

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