Introduction:

In a world of ever-increasing technological advancement and heightened manufacturing expectations modern machine shops are oftentimes caught bearing the consequences of unrealistic design tolerances. It's a challenge that most any machine shop contends with. Push back too much on customer requirements and no work will be awarded; accept any drawing as-is and pay the price of potential rejection during final acceptance.

With respect to part size Newell Corp has some of the largest capacity in the Pacific Northwest with horizontal milling up to 11' X 43' and vertical turning up to 216" in diameter. Part dimensions of this magnitude present a specific set of challenges. Meeting customer required *true position diameter* tolerances is oftentimes the most difficult and will be the focus of this exposition. The purpose of this study is to identify these manufacturing/measuring challenges, quantify the errors they produce and determine reasonable part specific true position tolerances. The data conveyed herein serves as an addendum to Newell Corp's standard terms & conditions. ***Tight tolerance GD&T will be considered "best attempt" unless deviation from the Newell Corp standard shop practices outlined in this document is explicitly agreed upon.***

Sources of True Position Error:

There are six main sources of positional error to contend with during machining operations of large metallic parts and weldments:

1. Part geometry/rigidity (as designed) – during post-machining inspection it is often difficult/impossible to return a part to its as-machined state after removal from the machine clamping fixture. *Newell Corp cannot predict nor completely eliminate error due to natural deflection.* In the case where dimensional accuracy must be maintained in a part's unrestrained state, steps should be taken at the design phase to ensure sufficient rigidity, adjustability, and/or to ensure work-holding setups match the final use configuration (i.e. annotate support points for the machining setup in manufacturing drawings).
2. Internal stresses in the material that relieve as material is removed. Stresses are induced in raw material in several ways: during material production at the mill, cold-working, welding, heat treating etc. This causes the part to "spring" out-of-shape once released from the machining setup. *Newell Corp cannot predict nor completely eliminate error due to internal stresses*. Steps should be taken at the design/planning phase to limit and/or relieve material of internal stresses.
3. Material is in a constant state of temperature change and this causes expansion/contraction of parts during machining and inspection. Newell Corp is not completely climate controlled but strives to maintain material and shop temperatures within ± 3° of nominal 68° F. The CTE of steel is valued at .0000065 in./in.-°F and .000013 in./in-°F for aluminum alloys. The general equation for expansion/contraction = (actual temp. - nominal temp.)*(CTE)*(part length).
4. Machine travel error caused by several factors including temperature variation, machine bed settling, scale drift etc. Newell Corp quantifies this on a scheduled basis and adjusts certain machine controller compensation values. It's observed that the machines gradually drift to an approximate worst-case error of ± (.003" + .0002"/ft) by the end of a calibration cycle.
5. Drill "walk" – drills drift off-course when travelling thru material. Many variables affect the amount of error including part material, spot drilling, drill material (HSS vs carbide), drill diameter,

speeds & feeds, peck vs. thru drilling etc. Because of the many variables involved Newell Corp assumes a commonly observed value of ± .001”.

6. Measurement error – Newell Corp utilizes Leica laser trackers to measure true position values. As outlined by the ISO 10360-10 laser tracker certification standard, maximum permissible error of a length measurement is ± (.0008” + .0001”/ft).

Error Approximations (refer to sources listed above for context):

1. N/A – cannot be predicted
2. N/A – cannot be predicted
3. Aluminum part → 3° F max variation from nominal → (3° F)*(.000013 in./in.-°F)*(part length in inches) = 0.000039”/in.

   Steel part → 3° F max variation from nominal → (3° F)*(.0000065 in./in.-°F)*(part length in inches) = 0.0000195”/in.

4. ± (.003” + .0002”/ft)
5. ± .001”
6. ± (.0008” + .0001”/ft)

Combination of Errors:

The purpose of this study is to quantify the *worst-case* true position diameter that could result when using standard machine shop practice, as measured with a laser tracker, with the part still restrained in the machine. For any part in question the values of lines 3-6 must be determined and combined. For example, a 6061-T6 aluminum plate with 8’ of distance from the datum(s) to the furthest away machined feature:

1. ***Unknown; based on part geometry.***
2. ***Unknown; based on material, amount of material removal, welding & stress relieving.***
3. (3° F)*(.000013 in./in.-°F)*(8 ft.*12 in./ft.) = ***.0037”***
4. .003” + (.0002 in./ft.*8 ft.) = ***.0046”***
5. ***.001”***
6. .0008” + (.0001 in./ft.*8 ft.) = ***.0016”***

Summing the bold values = .0109” of ***potential*** worst-case shift of a machined feature from its CAD nominal position. This is equivalent to **true position Ø = .0218”**, as would appear on an inspection report. If we remove measurement error, since the effect of this is theoretical and not a physical part attribute, then it is .0093” of **potential** stacked error. This is equivalent to **true position Ø = .0186”**.

Again, the above is *worst-case.* If we examine a more optimistic scenario we achieve better results:

1. ***Unknown; based on part geometry.***
2. ***Unknown; based on material, amount of material removal, welding & stress relieving.***
3. (1° F)*(.0000065 in./in.-°F)*(8 ft.*12 in./ft.) = ***.0006”***
    - Assumes material is steel rather than aluminum.
    - Assumes 1 degree temperature swing due to time of year and short machine cycle time.
4. .001” + (.0002 in./ft.*8 ft.) = ***.0026”***
    - Assumes machine accuracy is better from being compensated recently.
5. ***.001”***
6. .0008” + (.0001 in./ft.*8 ft.) = ***.0016”***

Summing the bold values = .0058” of ***potential*** stacked error of a machined feature from its CAD nominal position, equivalent to **true position Ø = .0116”**. If we remove measurement error the result is .0042” of **potential** stacked error, equivalent to **true position Ø = .0084”**.

Conclusion:

The analysis outlined in this study represents unlikely worst-case scenarios where all deviations combine in the same direction. It should be noted that actual true position results (found empirically) are often *half* of this value, and local deviations (spacing from hole-to-hole for example) are generally less than .003” from nominal. Due to periodic machine calibration cycles, and the issues outlined in sections 1 & 2, it is not standard practice for Newell Corp to inspect true position of features machined in the same setup unless contractual/quality requirements mandate it. Newell Corp does verify positional accuracy between operations, in the case where features are machined in separate setups. Newell Corp strives to eliminate and reduce all sources of manufacturing/measurement error, but the scenarios laid out above should be carefully considered by all customers.