Closed Loop Machining Model

The Closed Loop Machining model uses a new type of machining_workingstep to determine when the results of a machining operation need to be monitored and if so what tolerances need to be evaluated in order to decide if corrections must be made to the machining.

A measured_workingstep is a subtype of machining_workingstep that describes how a system can check and correct the result of a workingstep. If the machine tool being used is below the lower accuracy (its_lower_accuracy) then the machine cannot be expected to manage the workingstep and another solution must be found. If the machine is above the higher accuracy (its_higher_accuracy) then the machine should be expected to always produce a correct result and the measurement is not necessary.

If the machine is between the two accuracies then the measurement workplan describes how to check the result of the machining_workingstep and the repair workplan describes how to correct the results. If properly coded the measurement workplan will make a series of measurements that will result in values being placed into Nc_variables. At the end of the measurement plan the tolerance statuses (its_conditions) will be evaluated and if a tolerance is out of the allowed range then the repair workplan will be executed.

The tolerance_status entity connects a measurement to a set of measurement results (Nc_variables). The measurement results are used to evaluate the as_is state of the tolerance geometry. The as_is state is then used to compute a tolerance value. The tolerance_algorithm lets the user choose how this will be done when more than one method is available. The tolerance_status entity is an abstraction of geometry_tolerance_status, size_dimension_tolerance_status and location_dimension_tolerance_status because a location_dimension_tolerance needs both source and target surfaces.

A properly coded repair_workplan should fix the issue by changing the program using compensation operations and by machining the part again. The compensations may adjust the tool dimensions, or the depths and orientations of the toolpaths, or the geometry of the workpiece. In the latter case the workpiece size might be adjusted to fit measurements taken from an assembly.

Each compensation is tied to a tolerance status and if that tolerance is out of range then the compensation will be executed to correct the machining.

```
ENTITY measured_workingstep SUBTYPE OF (machining_workingstep);
its_conditions : LIST[1:?] OF tolerance_status;
                 // geometric or dimensional tolerances to be checked
its_measurement_plan : workplan;
                 // workplan to measure the tolerance
its_repair_plan : OPTIONAL workplan;
                 // workplan to repair the error if no plan then stop
its_lower_accuracy : SET[1:?] OF axis_travel;
                 // below this then cannot make this part on this machine
its_upper_accuracy : SET[1:?] OF axis_travel;
                 // above this then measurement and repair is not necessary
END_ENTITY;
```

```
// tolerance status links measured_workingsteps and compensation_workingsteps
ENTITY tolerance_status ABSTRACT SUPERTYPE OF (geometric_tolerance_status,
location_dimension_status, size_dimension_status);

ENTITY geometric_tolerance_status SUBTYPE OF tolerance_status;
its_tolerance : geometric_tolerance;
                            // geometric tolerance to be evaluated

its_estimate : OPTIONAL tolerance_value;
                            // measured value of the tolerance

its_measured_offsets : LIST[1:?] OF Nc_variable;
                            // measurements to be used to determine value
its_evaluated_geometry : OPTIONAL shape_element;
                            // computed using measured offsets
its_evaluation_algorithm : STRING;
                            // algorithm to determine tolerance estimate
END_ENTITY;

ENTITY location_dimension_status
its_tolerance : location_dimension;
                            // dimensional tolerance to be evaluated
its_estimate : OPTIONAL tolerance_value;
                            // measured value of the tolerance

its_origin_measured_offsets : LIST[1:?] OF Nc_variable;
its_origin_evaluated_geometry : OPTIONAL shape_element;

its_target_measured_offsets : LIST[1:?] OF Nc_variable;
its_target_evaluated_geometry : OPTIONAL shape_element;

its_evaluation_algorithm : STRING;
END_ENTITY;

// workingstep to correct tolerance errors
ENTITY compensation_workingstep SUBTYPE OF (workingstep);
its_input        : tolerance_status;
its_multiplier   : OPTIONAL REAL;
                      // scale error if necessary
its_operation    : compensation_operation;
                      // use error to change program, tool or workpiece
END_ENTITY

// Tree of TBD operations that repair the program
ENTITY compensation_operation
SUPERTYPE OF (toolpath_compensation, tool_dimension_compensation,
geometry_compensation);
END_ENTITY;

// change an axis or depth
ENTITY toolpath_compenstation;

// change a length, width or radius parameter
ENTITY tool_dimension_compensation;

// change the geometry of a workpiece
ENTITY geometry_compensation;
```