

DETAILED SPECIFICATIONS FOR MACHINE TOOLS

Numerical control units, specially designed motion control boards for numerical control applications on machine tools, numerically controlled machine tools, specially designed software, and technology as follows:

1. Numerical control units for machine tools, as follows:
 - 1.1. Having more than four interpolating axes that can be coordinated simultaneously for contouring control or
 - 1.2. Having two, three, or four interpolating axes that can be coordinated simultaneously for contouring control and one or more of the following conditions are fulfilled:
 - (a) Capable of real-time processing of data to modify the tool path during the machine operation by automatic calculation and modification of part program data for machining in two or more axes by means of measuring cycles and access to source data;
 - (b) Capable of receiving directly (on-line) and processing computer-aided design (CAD) data for internal preparation of machine instructions; or
 - (c) Capable, without modification, according to the manufacturer's technical specifications, of accepting additional boards that would permit increasing the number of interpolating axes that can be coordinated simultaneously for contouring control, above the control levels, even if they do not contain these additional boards.
2. Motion control boards specially designed for machine tools having one or more of the following characteristics:
 - 2.1. Providing interpolation in more than four axes;
 - 2.2. Capable of real time processing described in 1.2.(a) above; or
 - 2.3. Capable of receiving and processing CAD data as described in 1.2.(b) above.
3. Machine tools, as follows, for removing or cutting metals, ceramics, or composites, which, according to the manufacturer's technical specifications, can be equipped with electronic devices for simultaneous contouring control in two or more axes:
 - 3.1. Machine tools for turning, grinding, milling, or any combination thereof that:
 - (a) Have two or more axes that can be coordinated simultaneously for contouring control; and
 - (b) Have any of the following characteristics:
 - (A) Two or more contouring rotary axes;
 - (B) One or more contouring tilting spindles;

- (C) Camming (axial displacement) in one revolution of the spindle less (better) than 0.0008 mm total indicator reading (TIR);
- (D) Run out (out-of-true running) in one revolution of the spindle less (better) than 0.0006 mm TIR for grinding or milling machines, 0.0008 mm TIR for turning machines;
- (E) The positioning accuracies, with all compensations available, are less (better) than;
 - (i) 0.001° on any rotary axis;
 - (ii)
 - (I) 0.004 mm along any linear axis (overall positioning) for grinding machines;
 - (II) 0.006 mm along any linear axis (overall positioning) for milling machines; and
 - (III) 0.010 mm along any linear axis (overall positioning) for turning machines;
- (F) Capable of turning or boring of diameters equal to or greater than 2 meters.

3.2. Electrical discharge machines (EDMs);

- (a) Of the wire feed type that have five or more axes that can be coordinated simultaneously for contouring control;
- (b) Non-wire EDMs that have two or more contouring rotary axes and that can be coordinated simultaneously for contouring control.

3.3. Other machine tools for removing metals, ceramics, or composites;

- (a) By means of:
 - (A) Water or other liquid jets, including those employing abrasive additives;
 - (B) Electron beam; or
 - (C) Laser beam; and
- (b) Having two or more rotary axes that:
 - (A) Can be coordinated simultaneously for contouring control; and
 - (B) Have a positioning accuracy of less (better) than 0.003°.

4. Software

4.1. Software specially designed or modified for the development, production, or use of equipment controlled in sub-categories 1, 2, or 3 above.

4.2. Specific software as follows:

- (a) Software to provide adaptive control and having both of the following characteristics:
 - (A) For flexible manufacturing units (FMUs) that consist at least of equipment described in (b)(A) and (b)(B) of the definition of flexible manufacturing units; and
 - (B) Capable of generating or modifying in real time processing, part program data by using the signals obtained simultaneously by means of at least two detection techniques, such as:
 - (i) Machine vision (optical ranging);
 - (ii) Infrared imaging;
 - (iii) Acoustical imaging (acoustical ranging);
 - (iv) Tactile measurement;
 - (v) Inertial positioning;
 - (vi) Force measurement;
 - (vii) Torque measurement;
- (b) Software for electronic devices other than those controlled in items 1 or 2 that provides the numerical control capability of the equipment controlled in item 60.1 of Annex 3.

5. Technology

5.1. Technology for the development of equipment controlled in items 1, 2, or 3 above, 6 or 7 below; and of item 4.

5.2. Technology for the production of equipment controlled in items 1, 2, or 3 above, 6 or 7 below.

5.3. Other technology

- (a) For the development of interactive graphics as an integrated part in numerical control units for preparation or modification of part programs;
- (b) For the development of integration software for incorporation of expert systems for advanced decision support of shop floor operations into numerical control units.

6. Components and parts for machine tools included in item 3 as follows:
 - 6.1. Spindle assemblies, consisting of spindles and bearings as a minimal assembly, with radial (run out) or axial (camming) axis motion in one revolution of the spindle less (better) than 0.0008 mm TIR;
 - 6.2. Linear position feedback units (e.g. inductive-type devices, graduated scales, laser, or infrared systems) having, with compensation, an overall accuracy better than $600 + (600 \times L \times 10^{-3})$ nm, where L equals the effective length in millimetres of the linear measurement; except measuring interferometer systems, without closed or open loop feedback, containing a laser to measure slide movement errors of machine tools, dimensional inspection machines, or similar equipment; and
 - 6.3. Rotary position feedback units (e.g. inductive-type devices, graduated scales, laser, or infrared systems) having, with compensation, an accuracy less (better) than 0.00025° of arc; except measuring interferometer systems, without closed or open loop feedback, containing a laser to measure slide movement errors of machine tools, dimensional inspection machines, or similar equipment.
 - 6.4. Slide way assemblies consisting of a minimal assembly of ways, bed, and slide having all of the following characteristics:
 - (a) A yaw, pitch, or roll of less (better) than 2 seconds of arc TIR (Ref.ISO/DIS 230-1) over full travel;
 - (b) A horizontal straightness of less (better) than 2 μm per 300 mm length; and
 - (c) A vertical straightness of less (better) than 2 μm over full travel per 300 mm length;
 - 6.5. Single point diamond-cutting tool inserts having all of the following characteristics:
 - (a) A flawless and chip-free cutting edge when magnified 400 times in any direction;
 - (b) A cutting radius out-of-roundness less (better) than 0.002 mm TIR (also peak-to-peak); and
 - (c) A cutting radius between 0.1 and 5.0 mm inclusive.
7. Specially designed components or sub-assemblies, as follows, capable of upgrading, according to the manufacturer's specifications, numerical control units, motion control boards, machine tools, or feedback devices to or above the levels described in items 1, 2, 3, 6.2, 6.3:
 - 7.1. Printed circuit boards with mounted components and software therefor;
 - 7.2. Compound rotary tables.

TECHNICAL NOTE: *Definitions of Terms:*

- i. "accuracy" - Usually measured in terms of inaccuracy, defined as the maximum deviation, positive, or negative, of an indicated value from an accepted standard or true value.
- ii. "adaptive control" - a control system that adjusts the response from conditions detected during the operation (Ref.ISO 2806-1980).
- iii. "camming" (axial displacement) - Axial displacement in one revolution of the main spindle measured in a plane perpendicular to the spindle faceplate at a point next to the circumference of the spindle faceplate (Ref.ISO 230 Part I-1986, paragraph 5.63).
- iv. "compound rotary table" - A table allowing the workpiece to rotate and tilt about two non-parallel axes, which can be coordinated simultaneously for contouring control.
- v. "contouring control" - Two or more numerically controlled motions operating in accordance with instructions that specify the next required position and the required feed rates to that position. These feed rates are varied in relation to each other so that a desired contour is generated (Ref.ISO/DIS 2806-1980).
- vi. "digital computer" - Equipment which can, in the form of one or more discrete variables:
 - a. Accept data;
 - b. Store data or instructions in fixed or alterable (writable) storage devices;
 - c. Process data by means of a stored sequence of instructions which is modifiable;
and
 - d. Provide output of data.

N.B. Modifications of a stored sequence of instructions include replacement of fixed storage devices, but not a physical change in wiring or interconnections.

- vii. "flexible manufacturing unit" (FMU) (sometimes also referred to as "flexible manufacturing system" (FMS) or "flexible manufacturing cell" (FMC)).

An entity which includes a combination of at least:

- a. A digital computer including its own main storage and its own related equipment;
and
- b. Two or more of the following:
 - (A) A machine tool described in Annex 3, paragraph 61
 - (B) A dimensional inspection machine described in Annex 3, paragraph 52
 - (C) A robot described in Annex 3, paragraph 61
 - (D) Digitally controlled equipment described in Annex 3, paragraph 51

- viii. *“laser” - an assembly of components which produce coherent light that is amplified by stimulated emission of radiation.*
- ix. *“main storage” - The primary storage for data or instructions for rapid access by a central processing unit. It consists of the internal storage of a digital computer and any hierarchical extension thereto, such as cache storage or nonsequentially accessed extended storage.*
- x. *“microprogram” - A sequence of elementary instructions, maintained in a special storage, the execution of which is initiated by the introduction of its reference instruction into an instruction register.*
- xi. *“motion control board” - An electronic assembly specially designed to provide a computer system with the capability to coordinate simultaneously the motion of axes of machine tools for contouring control.*
- xii. *“numerical control” - The automatic control of a process performed by a device that makes use of numeric data usually introduced as the operation is in progress (Ref.ISO 2382).*
- xiii. *“part program” - An ordered set of instructions in a language and in a format required to cause operations to be effected under automatic control, which is either written in the form of a machine program on an input medium or prepared as input data for processing in a computer to obtain a machine program (Ref.ISO 2806-1980).*
- xiv. *“positioning accuracy” - Of numerically controlled machine tools is to be determined and presented in conjunction with the requirements below:*
 - a. *Test conditions (ISO/DIS/230/2, paragraph 3):*
 - (A) *For 12 hours before and during measurements, the machine tool and accuracy measuring equipment will be kept at the same ambient temperature. During the premeasurement time, the slides of the machine will be continuously cycled identically to the way they will be cycled during the accuracy measurements;*
 - (B) *The machine shall be equipped with any mechanical, electronic, or software compensation to be exported with the machine;*
 - (C) *Accuracy of measuring equipment for the measurements shall be at least four times more accurate than the expected machine tool accuracy;*
 - (D) *Power supply for slide drives shall be as follows:*
 - (I) *Line voltage variation shall not be greater than $\pm 10\%$ of nominal rated voltage;*
 - (II) *Frequency variation shall not be greater than ± 2 Hz of normal frequency;*
 - (III) *Lineouts or interrupted service are not permitted.*

- b. *Test Program (ISO/DIS/230/2, paragraph 4):*
 - (A) *Feed rate (velocity of slides) during measurement shall be the rapid traverse rate:*
 - N.B.: In the case of machine tools which generate optical quality surfaces, the feed rate shall be equal to or less than 50 mm per minute;*
 - (B) *Measurements shall be made in an incremental manner from one limit of the axis travel to the other without returning to the starting position for each move to the target position;*
 - (C) *Axes not being measured shall be retained at mid-travel during test of an axis.*
- c. *Presentation of test results (ISO/DIS/230/2, paragraph 2); The results of the measurements must include:*
 - (A) *Positioning accuracy (A) and*
 - (B) *the mean reversal error (B).*
- xv. *“program” - A sequence of instructions to carry out a process in, or convertible into, a form executable by an electronic computer.*
- xvi. *“real-time processing” - Processing of data by an electronic computer in response to an external event according to time requirements imposed by the external event.*
- xvii. *“robot” - A manipulation mechanisms, which may be of the continuous path or of the point-to-point variety, may use sensors and has all the following characteristics:*
 - a. *Is multifunctional;*
 - b. *Is capable of positioning or orienting material, parts, tools or special devices through variable movements in three-dimensional space;*
 - c. *Incorporates three or more closed or open loop servo-devices which may include stepping motors; and*
 - d. *Has user-accessible programmability by means of teach/playback method or by means of an electronic computer which may be a programmable logic controller, i.e., without mechanical intervention.*
- N.B. The above definition does not include the following devices:*
 - a. *Manipulation mechanisms which are only manually/teleoperator controllable;*
 - b. *Fixed sequence manipulation mechanisms which are automated moving devices, operating according to mechanically fixed programmed motions. The program is mechanically limited by fixed stops, such as pins or cams. The sequence of motions and the selection of paths or angles are not variable or changeable by mechanical, electronic or electrical means;*

- c. *Mechanically controlled variable sequence manipulation mechanisms which are automated moving devices, operating according to mechanically fixed programmed motions. The program is mechanically limited by fixed, but adjustable, stops, such as pins or cams. The sequence of motions and the selection of paths or angles are variable within the fixed program pattern. Variations or modifications of the program pattern (e.g. changes of pins or exchanges of cams) in one or more motion axes are accomplished only through mechanical operations;*
 - d. *Non-servo-controlled variable sequence manipulation mechanisms which are automated moving devices, operating according to mechanically fixed programmed motions. The program is variable, but the sequence proceeds only by the binary signal from mechanically fixed electrical binary devices or adjustable stops;*
 - e. *Stacker cranes defined as Cartesian coordinate manipulator systems manufactured as an integral part of a vertical array of storage bins and designed to access the contents of those bins for storage or retrieval; and*
 - f. *Robots specially designed for non-nuclear industrial applications such as automobile paint-spraying booths.*
- xviii. *“end effector” - end effectors include grippers, active tooling units, and any other tooling that is attached to the baseplate on the end of a robot manipulator arm.*
 - xix. *“run out” (out-of-true-running) - Radial displacement in one revolution of the main spindle measured in a plane perpendicular to the spindle axis at a point on the external or internal revolving surface to be tested (Ref. ISO 230 Part I-1986, paragraph 5.61).*
 - xx. *“sensors” - Detectors of a physical phenomenon, the output of which (after conversion into a signal that can be interpreted by a controller) is able to generate programs or modify programmed instructions or numerical program data. This includes sensors with machine vision, infrared imaging, acoustical imaging, tactile feel, inertial position measuring, optical or acoustic ranging or force or torque measuring capabilities.*
 - xxi. *“software” - A collection of one or more programs or microprograms fixed in any tangible medium of expression.*
 - xxii. *“tilting spindle” - A tool-holding spindle that, during the machining process, alters the angular position of its center line with respect to any other axis.*
 - xxiii. *“user-accessible programmability” - The facility allowing a user to insert, modify or replace programs by means other than:*
 - a. *A physical change in wiring or interconnections; or*
 - b. *The setting of function controls including entry of parameters.*

