SUPER-PRECISION TURNING CENTER: HIGH ACCURACY, HARD TURNING, MULTY-TOOL MACHINE TOOL

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INTRODUCTION

It follows from observation of modern machine tools stage of development that conventional technology (linear guides, ball screws, cast iron as material for machine major components, etc.) may still be successfully used to design and manufacture productive and very accurate machine tools. With a proper design, analyses, and manufacturing support the super precision (SP) and specially tuned (SP^2) Turning Centers have an area of application that, from our point of view, covers the gap between general precision (GP) and diamond turning machines, and partially may substitute or to be used in conjunction with grinding machines (see Fig.1).

Figure 1. Area of manufacturing application of Super Precision Turning Center.

With this goal in mind Hardinge Inc.(Elmira, NY) has developed theoretical and experimental tools, and established manufacturing and assembly procedures to design and deliver to the market a family of high productive SP machines that may be tuned up to customer (SP^2) accuracy requirements.

SP TURNING CENTER DESIGN

Requirements for the SP turning center design include:
- high accuracy, which means high stiffness. This requirement is very important because SP machines close the accuracy gap between general precision turning machines and diamond turning and at the same time bring turning accuracy in the range usually covered by grinding machine tools. High rigidity is also a necessity for hard turning operations (machining materials with hardness of 55-66 RC, which usually are machined by grinders).
- multi-tool and live tooling capabilities (turret type tooling system) for high productivity;
- Y axis capabilities (to perform off center machining);
- high metal removal rates, and effective chip removal.
- small footprint required for efficient use of customer floor space.

Distances between the X and Z axes rails, slides dimensions, linear ball trucks size, ball screw dimensions, etc. are optimized to provide the required static stiffness and geometrical accuracy of X and Z slides in the cutting point. The optimization process is based at distribution of lathe total compliance between its major components, which is known from experience. The need for multitasking prevents traditional lathe designs from satisfying modern requirements. Contemporary lathes should perform not only turning and drilling operations, but also milling, polygon milling, off center drilling, etc. These operations require not only live tooling but also additional axis movements. This means that a slide has to be added to the structure most often in direction tangential to circular turning surface (in Y direction). The addition of an extra slide to a traditional lathe design was done by a slide orthogonal to the X and Z directions. This way the additional slide has minimum effect at turning center stiffness. A base with high static torsion stiffness is the key to lathe stiffness in cutting point. Bases for Hardinge Inc. SP machines have the optimal stiffness to mass ratio due to a wide base with stiff inner structure and rigid pockets connected to the outer walls. Modern turning centers are designed as complicated machine tools with two
spindles and two or three turrets positioned in different areas. It is important to insure that the base provides adequate general and local stiffness to deliver the required relative stiffness between components involved in the cutting process.

Torsion stiffness of the base was significantly increased by adding material to peripheral part of the base. Polymer concrete (Harcrete®) was added in cavities, developed by double walls. The analyses showed that filling peripheral areas with Harcrete® affects not only torsion but also horizontal and vertical stiffness. This extra material also increased vibration damping capabilities of the base.

Decisions taken at the earlier stages of design process are checked and verified during design of machine tool components and full assembly by means of FEA. During this stage, every major machine tool component was analyzed by FEA with the goal to optimize stiffness/mass ratio. When performing these analyses the torsion and bending stiffness of every component in two planes was computed. Special attention was given to reduce local deformation and distortion of major castings because they affect stiffness in the cutting point that is positioned relative far from components because of machine layout.

GEOMETRY AND CUTTING VERIFICATION

High structural and kinematical stiffness of a SP machine allows successful use of linear scales as position feedback devices. The achievable geometric accuracy (position, straightness, parallelism) of SP turning centers can be compared with the accuracy of diamond turning and grinding machines. For example, results of the minimum step test (see Fig.2) comparable with results usually achieved at grinding machines with hydrostatic slides.

The contour accuracy of parts cut on SP turning center is comparable with accuracy, obtained on very expensive grinding machines (see Fig.3).

Data presented in Fig.2 and 3 are obtained on a production SP turning center that has a main spindle with 42 mm through bar capability, 16 stations top plate with live tools, second spindle, and has 14 inches Z axis and 7 inches X axis stroke. Weight of moving X-axis slide around 1,500 lb, and Z axis slide around 2,500 lb.

![Figure 2. SP Turning Center. X-axis slide. Standard minimum step test results (20 steps up and 20 steps down).](image1)

![Figure 3. Results of cutting a profile with large 5080 mm radii in part with hardness of 62 RC. Curve 1-by SP Turning Center; 2- by Grinder with hydrostatic slides; -- - - accuracy range of =/ - 0.75 micron; - - - theoretical profile.](image2)