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A Modular Approach to Diamond Machining

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ABSTRACT

Most equipment used for the machining of diamond turned optical components is developed using custom designed components. These components include spindles and slides which are created specifically for the design at hand. They have no other application. Careful design can, however produce machine components which have many uses without any sacrifice in performance. In fact, by designing modular slides and spindles with an eye towards a number of potential applications, the overall performance of these devices can be improved.

An example of this is a new, multi-axis diamond turning machine which uses modular construction and has a resolution of 1.27 nanometers. This machine has two identical hydrostatic slides which can be assembled in a number of configurations to create different machines. The work spindle can be used as a flycutting spindle or as the wheel spindle on a grinder.

1. INTRODUCTION

During the past two years, Rank Pneumo has developed a series of machine components which can be combined in a number of different ways to create diamond turning, flycutting and grinding machines with a variety of configurations. These components can also be used as building blocks to construct highly precise measuring or positioning systems.

I have spoken to this gathering in the past about the design of machine slides[1]. More recent papers[2,3] have addressed the design and construction of the two axis diamond turning machine which uses two modular slides in a staggered tee configuration. I have even suggested that these same components could be used to build a lathe capable of turning hardened steel parts using ceramic cutting tools.

2. SLIDES

The slides used on our experimental diamond turning lathe were designed so that they can be produced in at least three different sizes and in a number of different standard lengths of travel. The way covers can take several different configurations depending upon the constraints of the specific machine design.

Table 1. Standard Slide Sizes and Travel

Slide size	1	2	3
Dimensions, LxW	15x12	18x15	36x24
Height	7.0	8.5	15.0
Standard travels	1.0	1.0	-
	6.0	6.0	6.0
	12.0	12.0	12.0
	-	18.0	18.0
	-	26.0	26.0
	-	36.0	36.0

Because the slides are modular and can be positioned independently, adjusting the machine geometry is a simple task. The lathe has squareness between its slides of 0.2 arc seconds, an order of magnitude better than similar machines produced with dedicated slides.

Straightness of travel can be designed into modular slides. Because the slides are standalone components they are substantially more rigid than most other designs and this contributes to their geometric stability. The X axis of our lathe spans a gap of 16 inches yet travels straight within 4.5 microinches through its 12 inch travel. This was achieved without any handwork whatsoever.

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3. SPINDLES

Obviously, it takes more than a set of slides to make a machine tool. In addition to a slide or slides we generally require at least one spindle. Our set of modular components currently includes two spindles whose mounting dimensions are identical. These spindles were selected to cover a wide range of speed and load capacity.

3.1 Air bearing spindle

The first spindle is an air bearing device constructed with an integral, three horsepower motor. The speed of this spindle can range between 400 and 7200 rpm. The thrust bearing is located directly behind the front journal bearing so as to minimize the axial motion of the spindle nose with temperature yet maximize the radial stiffness. The AC motor is liquid cooled and thermally isolated from the spindle housing by a glass-epoxy thermal break. Vacuum can be transferred to the chuck coaxially through a non-contacting seal at the rear of the housing. To control the centerline height as the spindle warms at elevated speed the housing is designed to mount to the machine at the spindle centerline. The bolts which fix the spindle in place are arranged so that the spindle housing will expand axially from a point in line with the thrust bearing.

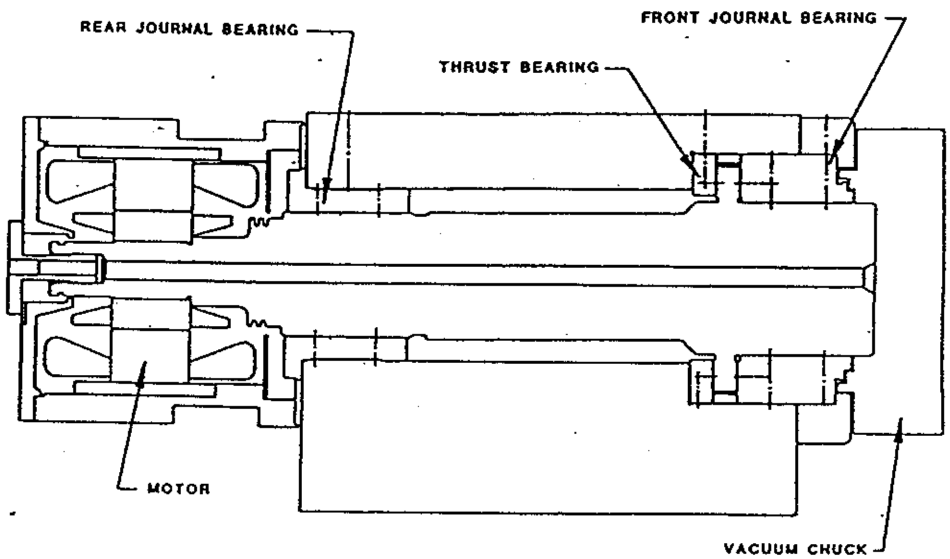

Figure 1. Air bearing spindle

3.2 Oil hydrostatic spindle

The second spindle has oil hydrostatic bearings and is powered by an integral, eight horsepower motor. The maximum speed of this spindle is 1800 rpm. This design also places the thrust bearing at the front although in this case, to minimize heating, the thrust bearing enclosed the front journal bearing. As in the air bearing design, the motor is liquid cooled and thermally isolated from the spindle housing. This spindle requires an hydraulic unit to supply the oil to the bearings at 250 psi. A heat exchanger is also necessary to provide control of the temperature of the oil.

I expect that the air bearing spindle will be employed as a lathe or flycutter spindle and as the wheelspindle of grinding machines. The oil bearing spindle will see use as a lathe spindle and as the workspindle on grinding machines. In addition to slides and spindles, we usually need some sort of position feedback system. Here we can use the entire range of available technology from resolvers and encoders through linear scales to laser displacement measuring instruments. Resolution can be nearly anything from 100 microinches to 0.05 microinches depending on the application.

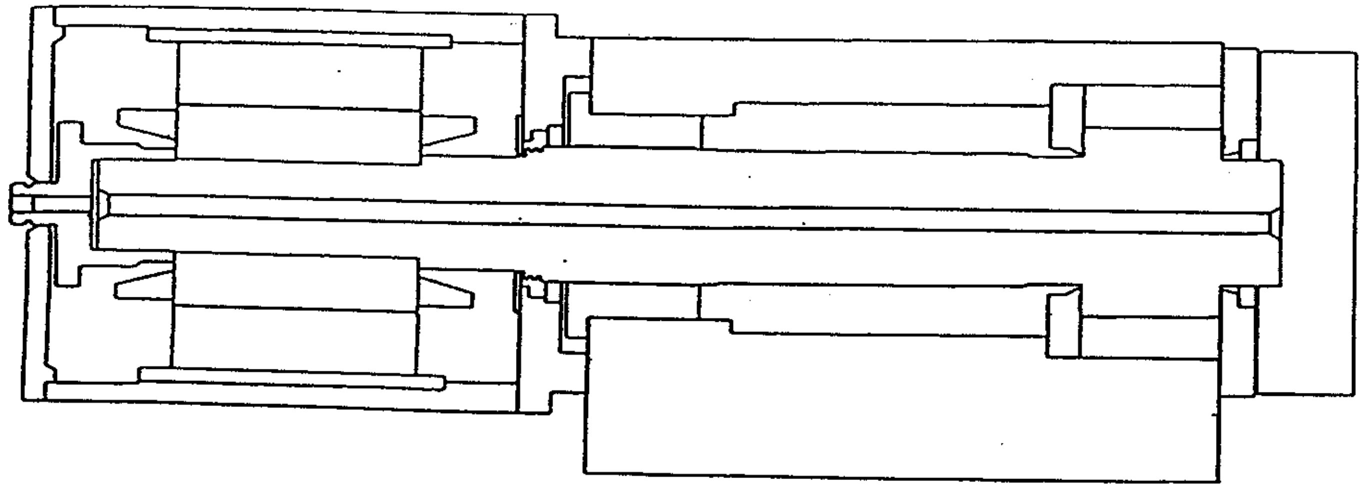

Figure 2. Oil hydrostatic spindle

4. MACHINE BASES

Bases for use with these modular components can be constructed to suit the particular application. Granite or epoxy concrete are obvious choices for high precision applications but iron castings or steel fabrications should also be considered if the job is less demanding.

5. APPLICATION EXAMPLES

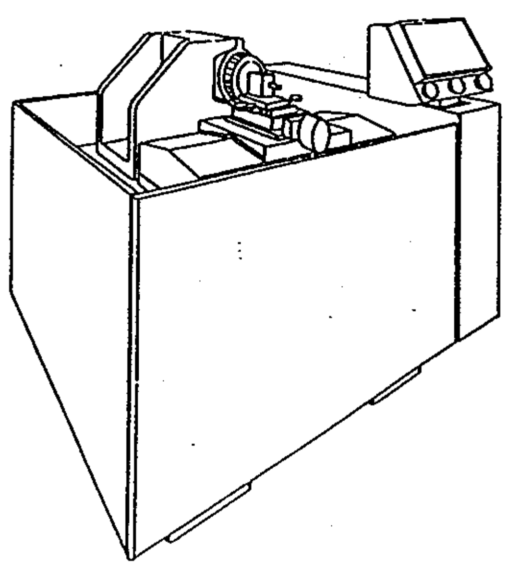

Figure 3. Facing lathe

5.1 Facing lathe

This very simple tool uses a six inch travel version of the mid-sized slide. The spindle chosen was the air bearing spindle. The base is natural granite, mounted on an air isolation system. The isolation system does not have self-leveling capability. An epoxy concrete riser supports the spindle which, in this case is mounted on its side because, for the application being considered, we did not have to cut to the center of the workpiece and thus control of the spindle center height was not of great concern. Coolant was supplied by a spray mist system. This machine did not require position feedback other than that provided by the non-contacting end of travel switches. The controller is a small, solid state programmable unit.

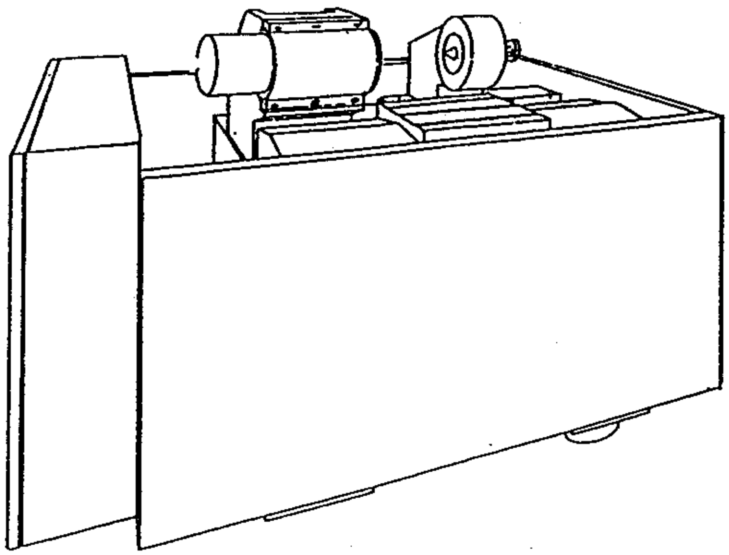

Figure 4. Drum lathe

5.2 Drum lathe

Another simple example, this design uses the same epoxy concrete riser as the facing lathe. In this case the riser is turned 90 degrees and combined with an 18 inch travel version of the mid-sized slide. This machine, which does not require extremely high work speed but turns heavier parts, uses the oil hydrostatic spindle. A natural granite base was used here but this time with a self leveling isolation system. The only new component here is the air bearing tailstock, which was designed especially for this application. This machine, like the facing lathe, did not require position feedback so the controls were similar to the facing lathe.

5.3 Horizontal spindle flycutter

Figure 5 illustrates a horizontal spindle flycutting machine. This example of a machine dedicated to the production of a single part uses the same 18 inch travel slide as the drum lathe, this time combined with the 6 inch travel slide from the facing lathe and the air bearing spindle to build a special purpose flycutter. The spindle is mounted conventionally in its cradle shaped support. As this machine was to be operated with an oil shower system for long term temperature control, an epoxy concrete base on self leveling isolation mounts was selected. This choice allows channels for coolant to be cast into the base. Only the fixturing and the base were designed from scratch for this machine.

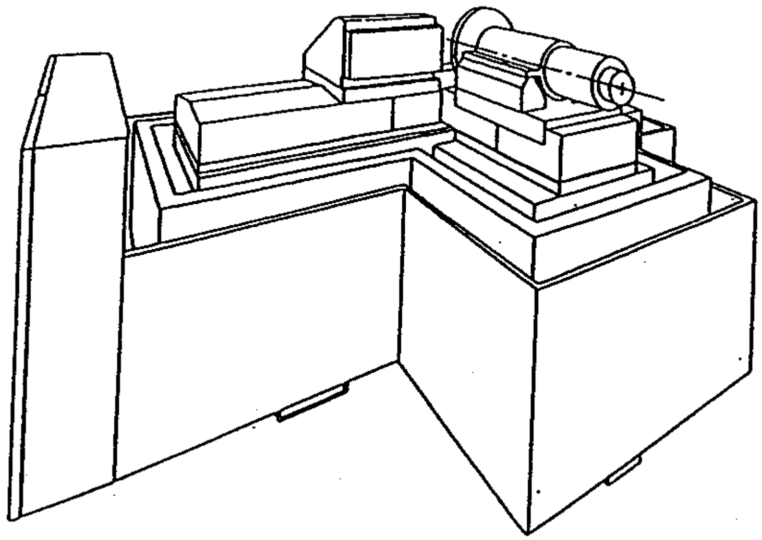

Figure 5. Horizontal spindle flycutter

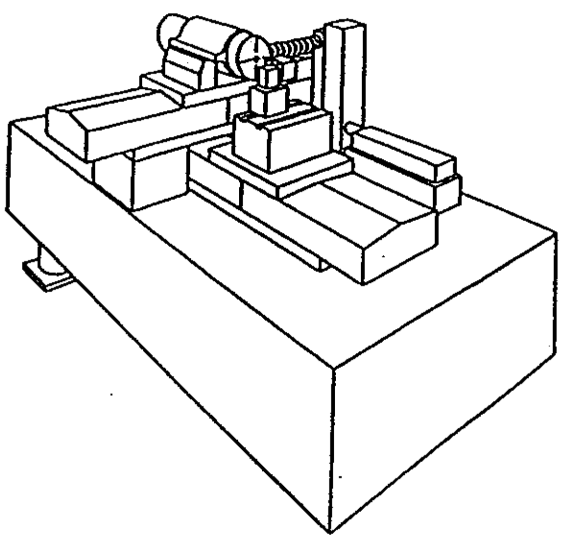

Figure 6. Two axis diamond turning machine

5.4 Two axis diamond turning machine

Designed to be a test bed for the latest technology in diamond turning, this machine uses two identical 12 inch stroke slides. The spindle is the 7200 rpm air bearing design. Position, as well as Z axis pitch information is fed back to the machine controller by the laser interferometry which, in this case, has a resolution of 0.05 microinches. The base of this machine is natural granite mounted on self leveling air isolation. The control system is a commercially available, full-featured CNC system.

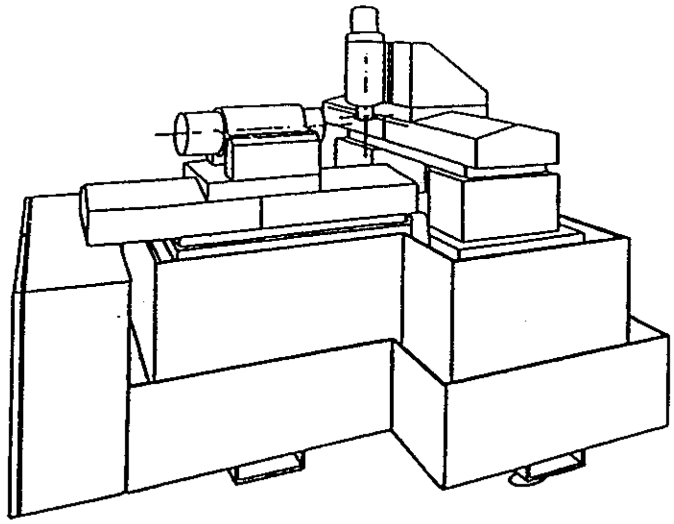

Figure 7. Two axis grinder

5.5 Two axis grinder for optical components

The now familiar staggered tee configuration is used again in this design for a grinder to be used to generate aspheric optical surfaces. Here rigidity is more important than a large swing so the workspindle is mounted on the lower of the two slides and the wheel-spindle is mounted vertically on the upper slide. This configuration puts the grinding wheel only inches from theX axis guide ways, maximizing the rigidity of the system. Because coolant is required for successful grinding of glass, the base for this machine is an epoxy concrete structure designed to handle a copious flow of cutting fluid. This particular application does not require the use of lasers to provide extreme position resolution so feedback is obtained from glass scales with a 4 microinch resolution.

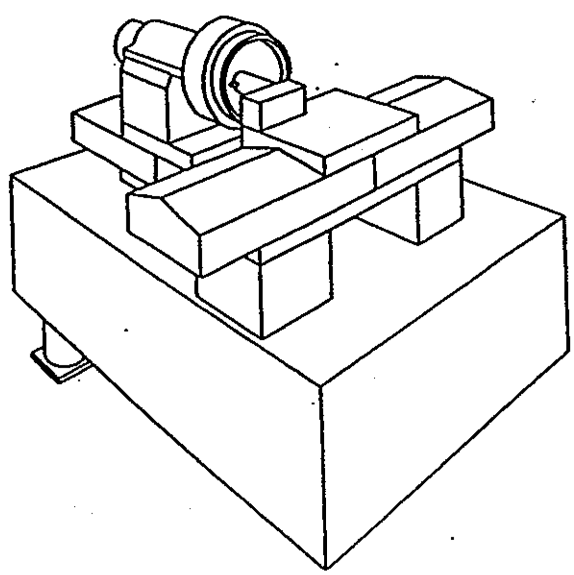

Figure 8. Hard turning lathe

5.6 Lathe for turning hardened steel parts

Looking much like the lens grinder, this production lathe is also designed with extreme rigidity as an important goal. The slides used are the same slides as those used on the diamond turning lathe. The workspindle is the hydrostatic design and is mounted to the lower, Z axis leaving the X axis to carry the tooling which is mounted as low on the slide as possible. Air isolation is unnecessary for this job. The base is epoxy concrete, the feedback is obtained from glass scales, and the controller is a commercial CNC unit.

6. Conclusion

By using pre-designed components it is usually possible to produce new machine designs in less time than would be possible if all of the parts were designed from scratch. The reduction in engineering effort can result in lower overall costs and, ultimately, better designs. These parts reduce the risk involved in a new machine design because, in most cases the design has already been "shaken down". In addition, manufacturing techniques can be optimized if families of similar parts are manufactured together as is often possible if designs have a high degree of similarity.

7. References

1. D.H. Youden, "On the Design of Ultra Precise Machine Slides" Proceedings SPIE, Vol 676, 1986
2. D.H. Youden, "Recent Developments in Diamond Turning" IMTS Technical Symposia, 1986
3. D.H. Youden, "A Progress Report on the Development of Ultra Precise Machine Slides" ASPE 1987 annual conference.