THE SEARCH FOR TRUTH & BEAUTY
OR,
ADVENTURES IN BEARING DESIGN

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INTRODUCTION

Over the course of the author's career, many different bearing systems have been designed. It is usual to present papers that deal with the best and newest ideas, novel approaches to engineering problems of the day with state-of-the-art solutions. In this case however, the author has chosen to take a trip back in time and single out for attention the odd and unusual designs, many of which, for a variety of reasons turned out to be dead ends. Perhaps they only appear to be dead ends when, in reality, they are simply incomplete ideas patiently awaiting some new and dedicated engineer to polish them off and devise successful applications that will properly employ them.

Some of the examples have been included because they are examples of clouded thinking, or perhaps design by committee. These are often associated with tales of horrorbilia evoking comments such as "What was I thinking!" or "I'll never do that again!"

Finally, some examples were chosen because they are success stories, and as such they need to be retold, much as the stories of heroic battles, which are passed from generation to generation, memorializing the memory of the participants.

WATER HYDROSTATIC SPINDLES

In the mid 60's at The Heald Machine Company, the author was involved with the design and application of hydrostatic internal grinder wheel spindles. The operating fluid of choice for this application was water. Pure, unadulterated H_2O. The choice was based on three characteristics of water: first, its low viscosity, second its high density, and third its high specific heat. The spindles operated at high rotational speeds, typically 20,000-50,000 rpm (1000 m/s) and the characteristics of water seemed ideal for controlling power consumption and heat generation. There were problems however. Water has little to offer in the way of lubricity, and was therefore very difficult to pump to high pressures. This was 40 years ago and materials were not available to build the pumps that are so common today. Water is also a very reactive fluid that attacks most metals. Worse than that, things grow in water, things that clog orifices and capillaries, things that smell bad.

Much effort was expended to identify rust inhibitors that were effective in both the liquid and the vapor phase of water. Additional effort was required to identify lubricity- enhancing additives that did not increase the viscosity of the water. Still further work was needed to find additives that would act as germicides and algaecides. In the end, all of this was abandoned, and the water bearing spindle program died a quiet death.

HYDRODYNAMIC / HYBRID SPINDLES

Hydrodynamic spindles were conceived as an alternative to the water hydrostatic spindles. The reasoning was that a significant amount of power could be saved if the oil used to operate the bearing did not have to be pumped to high pressure. The journal bearings were made of bronze and their bores were diamond turned using a crude fast tool servo so that the resulting bearing had four or five converging fluid wedges. The oil flowed through the bearings axially and at the exit end of the bearing there was a short section with reduced radial clearance that was not lobed. This produced an Adams style hydrostatic step bearing. The combination of the two effects provided a limited amount of load capacity when the spindle was not rotating and a very significant load capacity at operating speed. The thrust bearings were hydrodynamic step bearings that were created on the inboard ends of the journal bearings by die sinking recesses with an EDM machine.

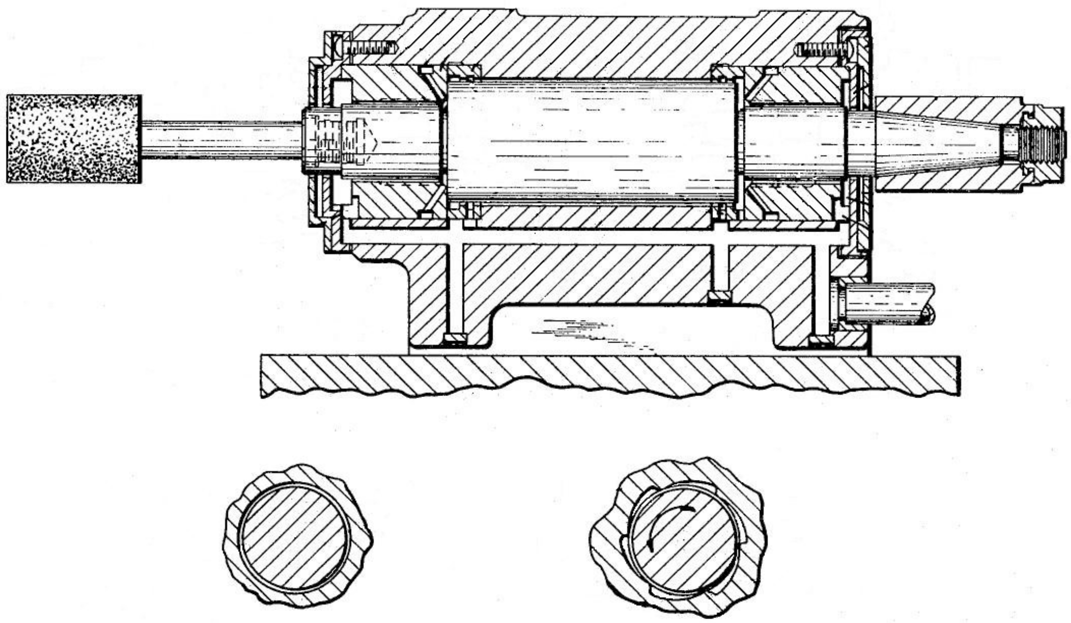

FIGURE 1: A drawing taken from the hybrid spindle patent

A number of these spindles were constructed, and none are known to have failed. At least one spindle is known to have survived 30 years in a manufacturing environment where it was, and may still be, operating on a daily basis.

This technology might benefit from a second look given the advances in machining and materials over the past decades.

SLIDE WAYS WITH ACTIVE COMPENSATION

Actively compensated slide ways were created to solve a problem on an internal grinder. On the machine in question the tooling was quite heavy, and could be moved from one position to another. Moving the tooling caused the centerline height of the work spindle to move due to the inadequate stiffness of the hydrostatic bearings that made up the machine ways. The solution to the problem was to design a valve that would allow the bearings supporting the work slide of the machine to have the same hydrostatic lift at two different loads.

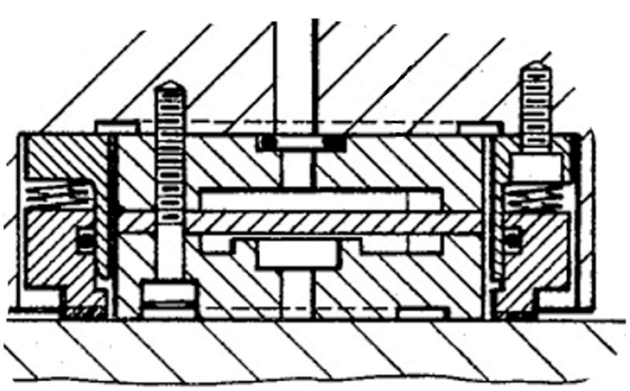

FIGURE 2: A hydrostatic bearing pad with active compensation and a face type seal.

The valve designed to solve the problem was comprised of a diaphragm that was positioned adjacent to a stationary annular land. Oil from the hydrostatic pump was supplied to the back side of the diaphragm and also to the area outside of the annular land on the front side of the diaphragm. The oil flowed through the gap between the annular land and the diaphragm and then out of the valve and into the bearing recess. By properly selecting the stiffness of the diaphragm and the gap between the diaphragm and the annular land, the bearing could be made to appear to have infinite stiffness.

There is a downside to all of this. The diaphragm is difficult to manufacture. The tolerances are unforgiving. This adds up to high cost. It is not good to fool mother nature, and it will cost you. Nevertheless, if high static stiffness is a requirement, this approach can be a life saver.

MULTIPLE DEGREES OF FREEDOM

One of the advantages of hydrostatic bearings is the ability to configure them to allow more than a single degree of freedom. Figure 3 shows a mechanism that was used to allow two axes of motion on a vertical spindle lathe. The mechanism shown provides the Z-axis and the X-axis motion of the tool post of the lathe. The work spindle is not shown but it lies on a line parallel to the large vertical drum of the tool support mechanism.

The lathe was controlled by the two cams shown on the left side of the illustration. The front cam controlled the Z-axis motion, and the rear cam controlled the X-axis motion. There were hydrostatic bearings around the drum, in the thrust bearing under the drum, and in the paddle that drove the rotational motion.

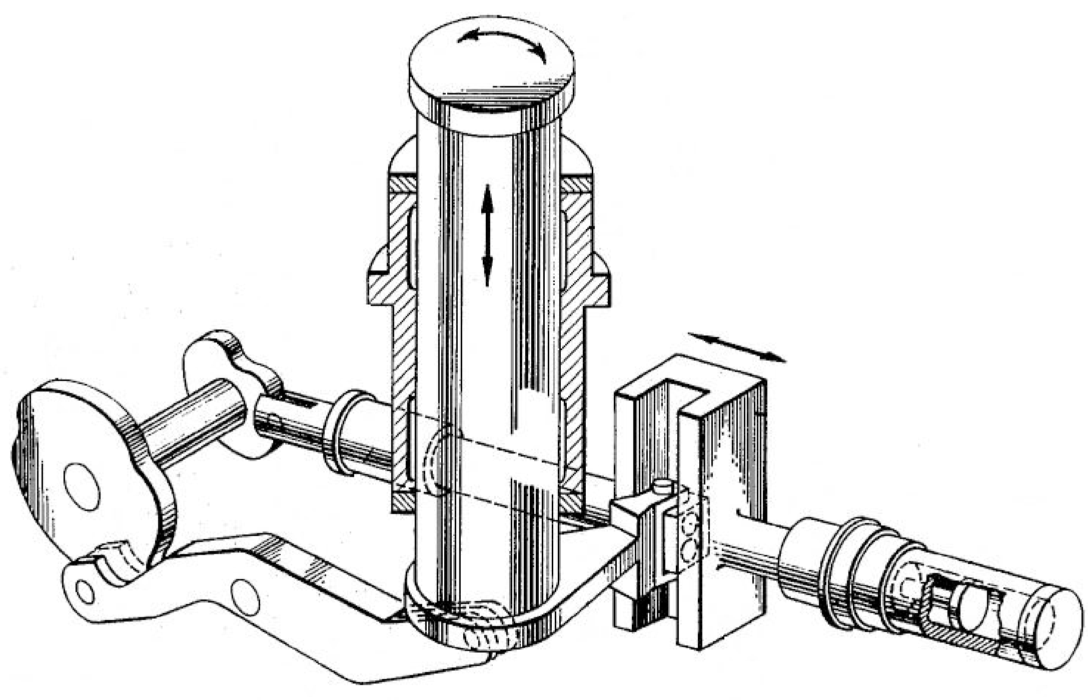

FIGURE 3: A two-axis hydrostatic drive system from a vertical lathe.

AIR BEARING ROUNDNESS SPINDLES

The challenge of designing a spindle for a roundness gauge is formidable. While spindles with synchronous error motion of less than 250 nm are common, spindles that can achieve error motion less than 25 nm are not. The breakthrough that made highly accurate spindles possible was the simple idea that the components of the spindles could be diamond turned. Turning the bearing components on a machine that had an air bearing work spindle meant that the roundness of the parts could be made significantly better than 100 nm. Some spindles had Adams type step bearings, and some used inherent compensation.

RESTRICTOR DESIGNS

There are probably as many ways to make a restrictor as there are people designing hydrostatic bearings. These devices must be small, inexpensive, deterministic, and adjustable. Designs include capillaries, orifices, flatted pins, porous plugs, screw threads, and various parallel plate arrangements. All of these variants are a sign that, up until now, no one has come up with a really good design. This is definitely an area where new ideas are needed.

CONCLUSIONS

Advances in materials and improvements in machine tools have made difficult things easier and impossible things possible The bearings that are designed today are not the same as the bearings that were designed years ago. Designers and the tools available to aid the design process have improved markedly. This, combined with a solid knowledge of what has gone before, will allow new designs that will exceed the performance of all that has gone before.

“Those who cannot remember the past are condemned to repeat it.”; George Santayana