REPAIR OF 140 FOOT, 150 TON, PRECISION HYDROSTATIC BEARING

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The situation:
In the manufacture of large electrical generators that are partnered with large steam turbines it is necessary to machine components to what qualifies as ultra high precision tolerances when considering the scale of the parts. An example would be armature shafts which are on the order 60 feet long, 6 feet in diameter and weigh in excess of 60 tons. These armature shafts require deep axial slots which are later filled with magnetic materials. Ingersoll is a manufacture of large custom metal cutting machine tools and was the original equipment builder of the slotter used by Siemens Power Generation in Charlotte, North Carolina. Hydrostatic bearing technology is employed to support and translate such large work pieces in a precision fashion. Unfortunately for some reason the hydrostatic bearings system had failed and scoring of the bearings under the table and of the way surfaces on the bed had occurred. Scoring in ether surface allows the hydrostatic oil to escape, preventing pressure build up under the table. With no pressure between in the bearing pockets in the table and the bed, the table bearing surface will bear directly on the bed way resulting in plain bearing contact and coulomb friction. Considering that the weight of the table and armature is more then 150 tons the friction force to be over come is significant, more then the hydrostatic drive worm and rack was designed for. So to continue operating the machine would have lead to failure in the drive system quickly. Siemens consulted Ingersoll who recommended that the base components be removed from the foundation and returned to Ingersoll in Rockford Ill. along with the table segments for re-machining on their large mill. This was estimated to take 8 months and with rigging and oversized transportation, cost more then the original cost of the whole machine. Siemens was naturally interested in a way to affect the repair in place. They were aware of Field Alignment Services and Training (FAST) and consulted them about possible "in place" repair options. FAST submitted a quotation and schedule that would have them in operation again with in several weeks. There is a high demand now for large generator sets and Siemens was not able to continue production with out the slotter. FAST received a purchase order with-in several days of sending a quotation.

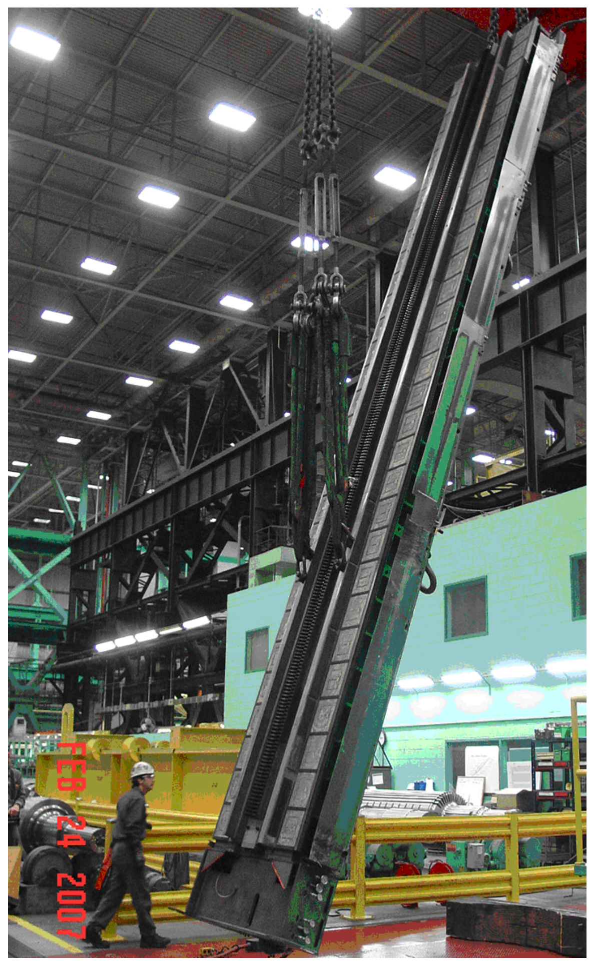

IMAGE 1. A 40 foot table segment with 30 hydrostatic bearing pads per way, being turned end over end. The table segment is fabricated from steel.

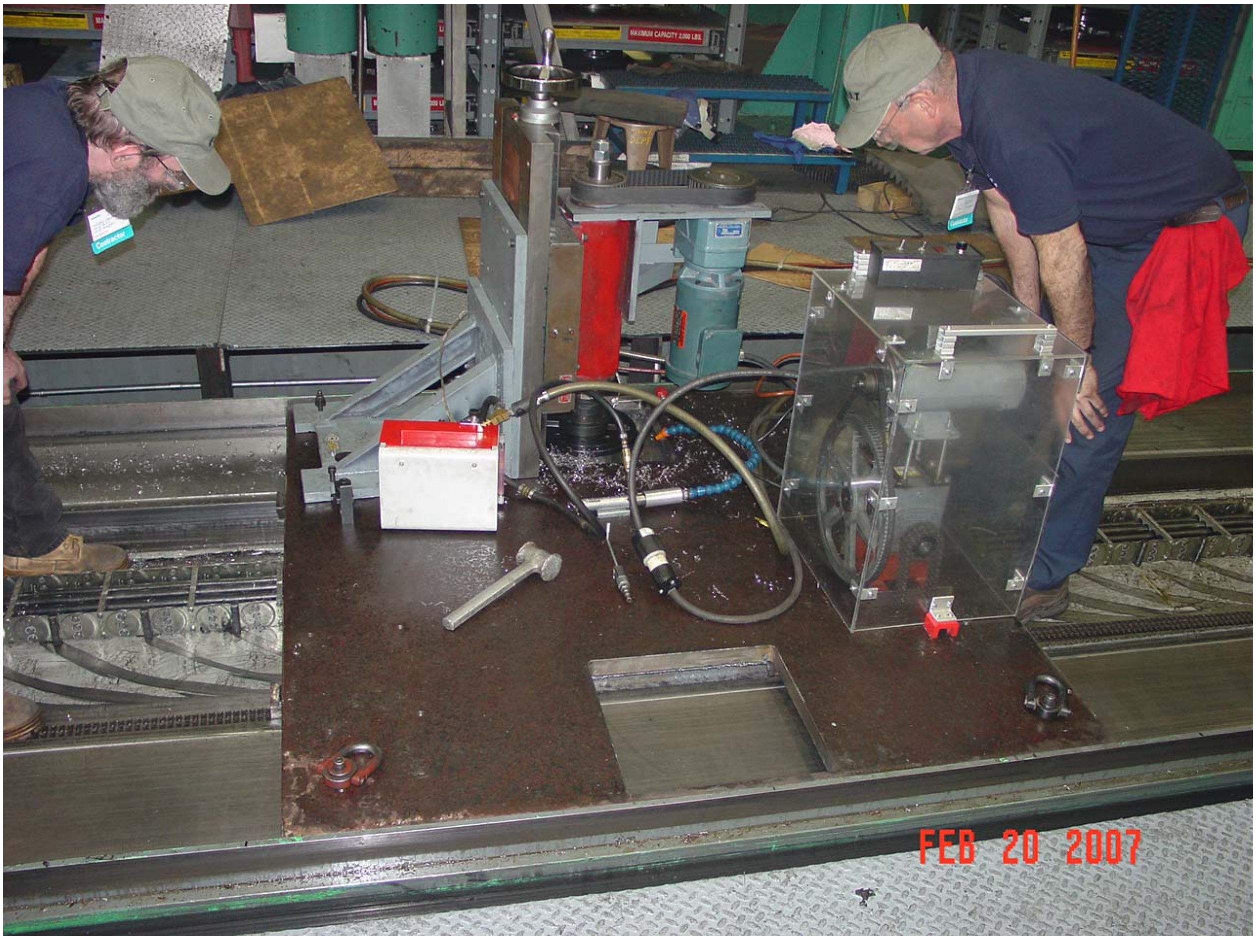

IMAGE 2. The temporary milling carriage, fit to accurate clearance surfaces with a moldable plain bearing material, with drive unit and milling spindle in operation. It was possible to carry a .002in deep cut for 140 feet.

The solution for the bed ways:
When Ingersoll manufactured the machine they designed and machined clearance surfaces that were machined in the same operation as the finishing cut on the ways, so these surfaces are parallel to the original ways. These reference surfaces are used to guide a temporary milling carriage which is used to machine wider guide surfaces next to the original ways. The temporary carriage is then refit to the new qualified surfaces next to the ways and a 50 taper milling head is mounted and used to mill the scores from the actual bed way surface bed way. The temporary carriage is just a simple flame cut plate of steel about 1.5 inches thick. The carriage is fit to the guide surfaces with a moldable plain bearing material, this is an enableling process because to pre fit the carriage by machining would have been virtually impossible and scraping the carriage to fit would have been very time consuming. The Carriage is driven by a variable speed DC drive which is coupled into a 50 to 1 reducer. The reducer out put is fit with a 16 tooth double row #60 chain sprocket. The mating double row chain is pinned at both ends of the 140 long bed way. The carriage has idler sprockets bolted under it that guide the chain up and over the drive sprocket then back down. This is a very convenient drive as the chain can be rolled up for transportation, then easily pinned to the bed to make for a temporary rack drive. The carriage speed may be adjusted from about 2 inches per minute up to 24 inches per minute. This temporary carriage and drive is stable for mounting an angle plate and a plain sliding Z stage for depth of cut adjustments. A 50 taper milling spindle is bolted to the Z slide and is driven with a 2hp variable speed ac motor with a reducer. The RPM required is relatively low as we are swinging a 12 inch cutter in order to cut a

10 wide way surface. Cuts this wide are serious milling, even at relatively low depths of cut (.015in. roughing cuts). Finishing cuts also require high rigidity as a “wiping” finishing cutter is used to achieve a fine finish and this type of cutter has a lot of surface contact making chatter likely even on finishing cuts of .001 to .002in. An advantage of this method is that the structural loop from the guide, carriage, angle plate, slide and spindle is only about 10 inches which is why the system has such high stability. To machine such a base structure on another large machine tool as Ingersoll was recommending requires a structural loop of some 10 meters. Such a structural loop must be massive to achieve anything near the same stiffness and is plagued with thermal errors. We were able to start a .002in. cut and 140 feet of cut latter still be cutting more then .001. This is also a testimony to the repeatability and following accuracy of the carriage. The flatness tolerance was .0005in. per 10 feet of bed way with a maximum of .002 per 100 feet. This was verified by an electronic level train.

IMAGE 3. 2 ways each 12 inches wide and 140 feet long, fabricated in steel. Notice the horizontal slotting spindles

The Table Hydrostatic solution:

The table is a 2 piece design, split near the center with one piece about 30 feet long and the other about 40 feet long to make a 70 foot table when keyed and bolted together. The table section in illustration 1 has 60 individual hydrostatic pockets. Ingersoll had glued phonolic pads to the underside of the table. These pads had a grove milled in which follows around the inside perimeter of the plate as seen along with the scoring in image 4.

IMAGE 4

Each grove had its own small constant volume pump. So as the table is loaded and the gap gets smaller this restricts flow from the pad but the pump wants to keep the same flow and so the pressure increases re-establishing the correct gap which is .0015in by the original specification. Because the hydrostatic worm in the bed and the rack segments on the table are not simple to adjust to a different table height we wanted to keep the same table height. Approximately .030in was removed from the bed ways in the milling operation so it was necessary to remove another .030in from the phonalic bearing pads in order to have at least a .060 thickness of moldable bearing material. This was relatively simple with a router and dust collector.

IMAGE 5

The table height had been carefully documented and this information was used to create metal shims (see image 5) that were placed between the reference surface on the bed ways and original clearance surfaces under the table. The table was set on the bed supported by the shims placed over every other web and the alignment and worm clearance were verified. The aim is to replicate the accurate bed way surfaces by molding to them, while holding the table in its correct elevation and parallel to the bed ways. This eliminates the need to machine or scrape the table bearing surfaces.

IMAGE 6

IMAGE 7 The as molded surface before trimming. Also notice that the hydrostatic worm rack segments have been replicated from a master using a moldable bearing material from the OEM

Moglice moldable bearing material will bond to the phonolic pads and fill the approximately .060in gap between the table and bed. Preparation of the bed ways includes application of release agent and the use of foam weather striping to contain the Moglice and separate the pads. The Moglice is mixed and poured on to the bed ways evenly, see image 6. The table is then set into the material on the bed and the alignment verified again.

Curing of the material occurs in about 18hr so the table is left until the next morning for removal. Results of the as molded surface may be seen in image 7 and 8.The excess material is trimmed and the hydro static groves are cut in with a router and template. The second half of the table is molded in a similar fashion except that it must be matched perfectly in height so that the keyways, which have almost no clearance, engage with out lifting either table from contact with the bed. In order to achieve this easily we make sure that the first table is in place and that the way surfaces are in intimate contact with bed. We set up to pour the second table right next to the first table so that once the table has been set the keys may be engaged before curing.

IMAGE 8 The surface immediately after release from the bed. Looking along the bottom of the image, part of a work piece cut on the machine is visible

IMAGE 9 Excess Moglice has been trimmed away the surface is ready to have the pressure grove routed in.

Thank you to Siemens Power for the use of the photos.