# Oral History of Mike Warner

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**Carlson:** A brief introduction. Computer History Museum is pleased to provide this interview of Mike Warner, who will discuss his computer technology experiences. Al Shugart, in an account of our industry, described Mike's development of the low-mass slider as one of the four great development items in computer disk drive history. Today, we'll hear from the person who actually did that. And Mike was the key person in the development of that technology. Mike's roles included Engineer, Manager, VP, President and Founder of a company. After a distinguished career of disk drives, Mike went on to contribute to the development of small-scale electronics, chip scale packaging and enabling ever smaller devices, and shrinking chip sizes. In addition to technical prowess, Mike was a natural leader, and one of the nicest guys you'll ever meet. I worked with him at five different companies over a 40-year period, and it's always been a pleasure. So, with that, let's start the questions. First of all, Mike, we're interested, of course, in the technology that you helped develop, but maybe give us a little background of your family and you started out in Oregon and Washington and wound up in Southern California, and then a first job at IBM. So maybe some early history.

**Warner:** Sure. I was born in Spokane Washington, and shortly afterwards, my parents moved to Oregon: First to a place called Warrenton, then Hammond and then Astoria. They are at the mouth of the Columbia River. My dad worked initially for the army. He also worked as the Chief Engineer on one of their forts. I grew up in Astoria. My dad had a business doing refrigeration and air-conditioning. I grew up with tools in my hand. My earliest memories are shining the flashlight for my dad and running to the truck and getting tools. That was kind of my world. When I was a tiny kid, there was an abandoned car across the street from us. We lived on a small farm, and I got to play in the car and take it apart. I got interested in mechanical things very early on. I attended Astoria High School. My mother had rheumatoid arthritis, and so at the end of my junior year our family moved to Southern California to Redlands near San Bernardino. I had been dating Laurie Nephew and we wrote back and forth for a year. After she graduated, she came down and went to school with me at San Bernardino Valley College. A year later, we got married, and a little while later, we moved to San Jose. I went to San Jose State. We both finished up there. I worked for a number of places like Thermatest Laboratories in the testing and general technical area, until I graduated. Then I got a job at IBM. It was one of two offers I had: GE and IBM. Fortunately, I chose IBM, because GE was working in the nuclear world and that was not going to be nearly as interesting as the disk drive world.

**Carlson:** And they closed that GE facility down.

**Warner:** Yes, so it is no more. I went to work in Quality Assurance at IBM, which was not what I had in mind. I wanted to be a Design Engineer. But I found that Quality Assurance taught me a lot of good lessons. I joined what's called a 2311 head disk line, and worked primarily on the head line. I learned the value of process control. I don't know if you remember, Bill, but we used a Western Electric handbook, and did X-bar and R-charts and means and standard deviations and had yield meetings and did all the stuff for quality support. Now the 2311 was an actual product. The head production was very manual. I mean, there were rows and rows and rows of ladies sitting in front of microscopes doing various jobs. The product itself, the 2311, used a stainless steel slider about the size of a nickel. It was curved with two bleed holes at the air bearing interface, and it had laminated metal cores that were ball-staked into the metal slider.

At that time, we did yields by the operator's inputs on how many they did, and how many were good or bad. The QA Inspectors filled out data sheets. Then the engineers would go over that data, and we'd send it in to be entered into a database. It was all manual. We got a computer report back, but all the entry and all the numbers were generated by hand. I remember going there and meeting the first Manufacturing Manager, Des Owens, and his technician Don Smith. They were very welcoming. It turns out that Des was working as a Manufacturing Manager, but he was educated in Finance. IBM took everybody they could. They were trying to hire people at that time to fill their plant on Cottle Road. I would say I walked away from that with an appreciation that the engineers have to learn how to properly spec things, because the operator in the line looks at a piece of what she's done, and makes a judgement if is it good or bad. And if she's too critical, she"s throwing lots of good product away. And if she's too lax, you're creating problems downstream. So that was one lesson. The other was to, wherever you can, have processes that you can actually measure and control. Visual inspections are notoriously unreliable. So those early lessons actually were very powerful in my design decisions as I went on as an engineer. I think I was quite fortunate to join the quality organization.

**Carlson:** I know we made the disks at IBM, but were the heads were provided by outside firm?

**Warner:** No, the head line was completely within IBM. We got photo-etched mu-metal, and we coated it with resin, laminated it, pressed it together, wound our own coils and put them on the mu-metal cores. What we would do is bend the pole tip stack, slide the coil over and then bend it back. Now it turns out when we had these sharp edges we would cut the coil sometimes. That's where I met Karl Elser who I later found came from Germany. They had the same problem in Germany, and what they found was a little plastic tube could slide over the magnetic core, and then put the coil on it, and that dramatically improved the yield for that particular problem. You can see that sliding the coil down a very sharp edge is bound to nick it. So, by putting the tube on first, you fix that problem. Anyway, one of my early jobs was also heading the Yield Committee. We had a Second Level Manager Stan Disbro. They called him The Silver Fox because of his silver hair, and he was on everybody's case: on our case, on the Manufacturing guy's case, everybody's case, because he was ultimately responsible to get the numbers out and meet the commitments for the head line. It was a fun time, and interesting, and my first experience inside of a really large corporation.

**Carlson:** Good training. I remember I was hired by John DelFavero, I don't know if you remember him.

**Warner:** Oh, yes,

**Carlson:** And he used to have the equivalent of Yield Meetings when we had problems. And seemed like every summer, the disk line would have problems.

**Warner:** Yes

  

**Carlson:** But before you get to the IBM stuff, what got you interested in technology? You graduated, as I recall, as a Mechanical Engineer.

**Warner:** Yes.

**Carlson:** And did you have a technical career in mind when you were growing up?

**Warner:** Well, I decided, actually, when I was a freshman in high school. We had a class that helped prepare us, taught us how to study, you know, take notes. We also worked on what did we want to do, what vocation. I decided then that I wanted to be a Mechanical Engineer. And that was always in my mind except for a short time in college when I wondered if I wanted to be a psychologist. I took an aptitude test and it said I would be a better engineer than a psychologist. <laughter>

**Carlson:** I did the same thing. I did one of those aptitude things. I was not going to be a minister, that was for sure.

**Warner:** IBM had really a lot of interesting people. Let me tell you about my first group. There were guys in my QA group, like Cyril Glushkof, and Wayne Pierce, the Manufacturing Engineering Manager, Mike Peterson. I think Eric Solyst was actually the guy on the Development Engineering side. It was also, I think, about the time I met you, even though the 2311 was in production for you, just like it was for me. I think we got closer when we worked on the 2314. I think I mentioned most of the other names of the people that I recall off the top of my head.

The next product coming down the line was part of the System 360, and that was going to be the 2314 program. The 2314 program was another program with disk packs. Disk packs were great, because in theory, you could have infinite storage by swapping out disk packs. That's the good part! The bad part was that when you swapped out disk packs, then every head had to be able to read every other disk pack. And if one head was contaminated, then you contaminated every pack installed on that drive. Sometimes one disk drive would be damaged, so you'd put a pack in and it would crash the surface. Then you'd put another pack in and it'd crash the same surface and so forth, until you figured out, "Oh, the reason I'm not getting any data is because I have a bad head on my drive." Anyway, the other issue probably even more important from a design standpoint was handling all of the tolerances that were involved. As you moved from pack to pack, you had spindle tolerances and disk tolerances and thermal issues and so forth. These early heads were done with a write-wide, read-narrow so they had a tunnel erase. Which means that they would erase either side of the track. So when you tried to position the head, and if it was mis-registered, it didn't try to read adjacent track information. It would just read its own track information. So that’s why you would trim the tracks. That allowed the use of things like hydraulic actuators, and mechanical stops. So they'd move the actuator to a position and mechanically detent it, or stop it and read the tracks. Well, the 2314 was just a higher density/capacity version of the 2311. Instead of six-disks per pack, it had eleven-disks per pack.

**Carlson:** And taller.

  

**Warner:** The 2314 was taller. It was bigger. It was faster. It was everything better. And the 2314 also, from a head standpoint, changed from the stainless steel curved slider to a round ceramic slider, that we called the monkey face. It was white aluminum oxide (alumina), and instead of using mu-metal laminated cores, we used a ferrite core which turned out to be a significant change. It used also a mu metal erase core on either side, so that we'd trim the tracks, so we still had the advantage of trimming. But it was-- again a very manual process. It was done with dozens and dozens and dozens of ladies using microscopes to assemble things. Technically it had one fatal flaw as far as the heads were concerned. That is the ferrite core (and the side race elements were) was bonded to the alumina slider with epoxy. When the weather was humid, the epoxy would swell, when it dried out the epoxy would shrink and with temperature changes the epoxy would move. It was just terrible because you'd have a good head one day and a bad head the next, and vice versa. And manufacturing started learning, "Okay, if we save them up for this kind of weather, we can get a better yield," and they'd save them up. And so lots of games were played like that. We wound up requiring every head have mechanical stylus profile traces of the pole tip. Then we sent the heads through temperatures cycles, through hot and cold, and then making traces with the stylus instrument again. It was a very long painful process for us. However, it turned out to be quite a successful from a machine standpoint. And the design person and leader of the head program was a guy by the name of Dwight Brede. I also learned a lot about standards at this point. And that was because our test yields varied so much, we had Gold standards, Silver standards and Working standards. So we would take a Working standard and periodically during the day run it on the tester and the same thing for heads (to check tester calibration) . We had Gold, Silver and Working standards, in order to make sure everything was calibrated, because people couldn't believe that these outputs were varying this much (due to epoxy effect on the core position in the head). So standards, became very important, particularly on that program and then going forward.

I would like to spend a minute talking about the ferrite core.

**Carlson:** Go ahead.

**Warner:** The ferrite cores were being made in Poughkeepsie, New York. And it was done in a batch fabrication process, where two pieces of ferrite were glass bonded together with a gap, and then they were sliced, and then sliced again. So we had U-shaped cores with a throat and a gap that were all glassed together. Like in any manufacturing process, problems come and go. And we had stuff that we called "crap in the gap," and it was spots of unwanted stuff in the gap. I made a couple of trips to Poughkeepsie. That's where I met a gentleman by the name of Miles Cook, who ran that operation. And it became significant, because for the next programs we were going to use ferrite cores. The Ferrite Core Division was located on the East Coast because they made core memories (for main frame computers). Well, core memories were going out, and they had all these guys who knew about ferrite. So Miles Cook and Hal Turk, who was a ferrite expert, and Dr. Dwayne Seacrest, who was the glass expert, and Walt Nystrom, doing magnetics, all moved out to San Jose to support us on our next products. These products were the 3330 and the 2305.

Here's one story, I think that's kind of interesting about the 2314. As we were going into product tests, we would get these random errors all the time. And people couldn't figure out what the heck was going on.

  

And, there were actually two phenomena that were taking place. One, you probably knew about. That was the Mount Umunhum radar station.

**Carlson:** Yeah, I was going to mention the radar.

**Warner:** As the radar antenna went around, it'd (on the oscilloscope screen) come with a blip, blip, blip which were errors. We had these long pigtail electrical leads that went from the head arm to the read/write channel. In addition to the radar, while we were accessing, we'd get some other random errors. And then someone remembered that the wires from the heads were put inside of plastic tubes. And those tubes would touch one another and there'd be a static electricity discharge. So kind of like overnight we came with-- or someone came up with a solution of putting a conductive metal spring that was attached to the arms around each of the plastic tubes.

**Carlson:** Oh, that's why it's there.

**Warner:** And that supported all these tubes. And it also shielded from the Mount Umunhum effect, and it also obviously stopped the static electricity, because it was grounded. So the next couple of machines had these wire springs around the tubes holding the wires.

**Carlson:** I remember seeing that, and I didn't know why. For the people who may not be local, you might explain what Mount Umunhum is all about.

**Warner:** Oh, Mount Umunhum was a military installation with a great big radar station up in the West foothills. We could see it,

**Carlson:** You can still see it. And now it's a park. You can go up there.

**Warner:** It used to be that the government would deny it was there, even though you could see it. But it was a facility that was there to scan the coast for enemy aircraft.

**Carlson:** They had very powerful radar. I remember our contractor's television would go screwy once in a while. And he got on a first name basis with a guy up in Mount Umunhum, he's say, "Hey, point your aerial somewhere else!" <laughter>

**Warner:** A few people I forgot to mention include Jack Payne who was my manager when I was still a QA guy

**Carlson: Yes**

**Warner:** And the lapping machines that were invented by Lothar Schicker. I don't know if you remember Lothar?

**Carlson:** Oh, yes!

  

**Warner:** And oh, Ray Herrera, and George Santana were in the Development Lab. I don't know if you remember it, but because this was such a difficult head to build, we had one of the lab technicians, Yvette, I don't remember her last name.

**Carlson:** Oh, yes, I remember her.

**Warner:** She came over and trained operators. Basically, we were hiring housewives. Some of them had done lots of sewing, and things like that, and were quite adept, and others were not. So, we would have to give them jobs that would match their skills. This was also where I learned to put in long, long hours. This was System 360 days. An enormous amount of pressure was put on us to deliver. And of course, we were trying to deliver on a product that had very, very poor yields. So, I spent, long days and long nights and was very involved with a number of the solutions to various problems. As a result of that, I got an Outstanding Contribution Award. At the end of a program, the Development Lab would have a big party, invite everybody there, and I was one of three guys from Manufacturing that was included, so I felt really very privileged. It was a good program for me. I learned a lot about electrical testing and about stylus instruments and measuring. We'd measure curvature with optical flats and monochromatic light.

**Carlson:** Oh, you mentioned in your little history here something about fretting corrosion?

**Warner:** Oh, yes, that's another story. We were concerned about the nylon load point touching the back of the ceramic slider and that we would get fretting corrosion. Because the contact point wasn't in quite the same plane as the suspension gimble. This was true for both this program and the next program. So QA and the manufacturing engineering guys built a machine that had a (small head sized) stage that would pivot. What it was supposed to do is make a motion like a head would do flying over a disk. And there were, I think, twelve stations on this machine, and it was run by little motors and it would be running 24 hours a day. It was so noisy we kept it in the basement of Building 15. I would go over there once a week or so and check on it. And what we really found was the fretting corrosion wasn't nearly as much of a problem as it was keeping the machine going. The testing wore the machine out all the time. And it was a well-designed machine. It just shows the lengths that IBM went to for reliability.

**Carlson:** Those were made of stainless steel, why would they corrode?

**Warner:** Oh, if you have stainless steel rubbing or wearing, for example, then the byproduct of that is particles that always looks rusty.

**Carlson:** Little chips **?**.

**Warner:** Looks like rusty dust. So we were concerned; one, that there would be dimensional change; and two, that it would be a source of contamination in the file.

**Warner:** After the 2314 I moved to the Development Lab. That's where my heart was from my engineering education. I wanted to design things. I got a job working for Eric Solyst on the 2305 program. Now, this was a nine-element fixed head. And it was going to go into a fixed disk stack. The disks were going to spin at 6,000 rpm, and they would have either a head per track, or a head on either side of the disk for two heads per track. So, you would only have half the rotational latency. The challenge was to make heads such that one head could read the other heads' information, and that they could be lined up properly. And it meant for some very tight tolerances. Eric Solyst came up with a technique of making the heads with kind of an extension of ferrite core work in a "batch process". He made the body of the slider all of ferrite. There's a description of that process in the books I showed at the beginning (IBM Journal of research and development pp353-846 Vol25, No.5, Sept,1981 25 anniversary issue). And they were glass bonded together, and by slicing and dicing and grinding the ferrite, you'd make a little head that was, roughly a half-inch long by three-eighths inch wide, with nine elements on it. It had extremely tight tolerances. For example, the air bearing was a tapered flat bearing, and it was made by lapping with what we called a sine plate. We'd lap the slider surface flat (and to the proper throat height) then we would tip the whole head slightly. Then we would lap the next surface for the leading taper. The way we controlled the amount of lapping is that we had a ceramic ring around the fixture that was a stop ring. So, as it's lapping away, as soon as the sine plate hit the stop ring, which has much larger (ceramic) area, it would stop the lapping process at the appropriate end point.

One of the kind of funny stories for this program is that Manufacturing had started an Advanced Manufacturing Engineering Group. And the team had looked at the Zeus, or 2305 head, and looked at all the tolerances. The gap tolerance was micro-inches, the flatness was micro-inches. A micro-inch is a millionth of an inch. The indexing was tenths of a thousandths of an inch. And they said, "There's no way we can make this. There's no way in the world we can make this." And they said, "In the first place look at the 2314 yield, which is a ferrite core," and they said, "You have nine of those, so we'll take the 2314 core yield to the ninth power", and the yield would be near zero.

**Carlson:** Zero.**?**

**Warner:** Yes, but obviously, it wasn't true, because they were completely different. And we had processes that were set up in the lab that we transferred to Manufacturing that virtually gave, I think, near 100 percent yields. We did a massive amount of work on indexing. We took relatively inexpensive grinder/slicers and put on either laser interferometers, or Heidenhain glass scales, so we can index very, very accurately. I mean, when I say index, we can index to like ten micro-inches or something like that. Then we had processes for dressing the wheels. We did a thing for the apex that needed to be very smooth with what's called a cup grinding wheel. And the cup-grinding wheel would literally produce a very smooth shiny surface at an angle. And this had to be done, I think, I can't remember, it was a 45 or 30 degree angle or something like that.

**Carlson:** How did you convince management to go ahead? Manufacturing and Engineering says, "No, we can't do this."

**Warner:** I think we did it by demonstrating what came off the processes. We had lapping machine processes such that it was easier to make them flat than it was to measure them, to be honest with you. And so we used, again, monochromatic light to measure flatness, under an optical flat surface for inspections. We also did flying heights measurements on the heads. The flying heights were done, flying on a spinning disk made of glass.

**Carlson:** I remember those.

**Warner:** And so the head would fly over a glass disk, and a monochromatic light source was used. We would change the light frequencies to see how the band shifted and we would know what the spacing was. When they saw what we had done for the processing machines, Manufacturing Engineering could say, "Yeah, we can do that." and so they set up production lines. They also did the ferrite manufacturing. So that was no longer done in Poughkeepsie, it was all done in San Jose. They ground the powders, mixed it, sintered it, and then sliced it, and did all the related work.

**Carlson:** I didn't know that.

**Warner:** It became what they called the “stiff-finger” line. That means that you'd set the machines up, and there'd be a whole grinder bed with hundreds of pieces on the surface, and an operator would push the button and then the machine would go do its job, whether it was slicing, beveling or grinding, whatever it happened to be. And one operator could run four machines. I mean to say it was not completely automated, but it was--

**Carlson:** Semi-automated.

**Warner:** Yes, semi-automated. And this becomes very critical, being able to efficiently process these ferrite heads. I think I mentioned that Eric Solyst was the inventor of this “batch process” and he was the development department manager. We had guys on the team like Elliot Pflughaupt. Elliot was responsible for the head loading and for specification generation and, standards generations. The air-bearing design was done by Tom Tang. George Pal, worked on the program. John Ramos did the drafting. There were a number lab technicians. I did process and measurement development and tooling design.

**Carlson:** You mentioned glass cracks.

**Warner:** Ah, yes. We had a problem that we'd get small cracks that were observable under the microscope. This was a case of how to interpret tight specifications. Such as how flat is flat? How round is round? How clean is clean? How cracked is cracked? Some of those are very difficult to define. To say, "I looked at this, it looks clean." Well, it may have all sorts of stuff on it. So usually what we would do for those kinds of things is come up with some kind of a test for it. Like cleaning: we found when we put things through an ultrasonic cleaning process, one batch or one line would really look great, and the other line looked terrible. We said, "What's going on?" Well, it turns out we had different brands of ultrasonic cleaners. So then somebody came up with the bouncing ball test. I don't know if you remember that. We would put a beaker, a flat-bottom beaker with little BBs in it, and then some lines on the side of the beaker and you would set the beaker in the ultrasonic cleaner and then measure how high the beads went. <laughter> So if they went two millimeters high, that was one measurement. You'd go to another ultrasonic and measure at four millimeters high. And then you'd say, "Oh, yeah, I need to have at least four to get the parts clean." There were all kinds of crazy tests that were done that way. But anyway, on the cracks, we had to develop some sort of criteria of what was good and what was bad. And while we were developing that, we were doing tests. We would load and unload heads on the disk, because we were afraid that the crack would grow. So I personally went on the end of the line and viewed every crack and put it into a go/no-go or test bin. I did that day and night. Lou Blendermann would come out (at night) and say, "How're you doing? How're we doing on it?" He was my second line manager at the time. And so it was like this until we figured out that most cracks actually were not a problem. They didn't grow and it was just cosmetic. The crack actually had released whatever stress was there. There was still enough good material. It wasn't like the cracks we get in metal, from fatigue or whatever.

This was my first time to be in the Development Lab. and to make these early heads, IBM hired watchmakers and really skilled modelmakers. We took the best technicians from the manufacturing line and brought them over to the lab. And there were guys like Chuck Snyder and Chuck Blackly who were watchmakers. Alta Wright and Valerie Peterson were assembly operators in the lab. One of the things we had to be careful about is these people were so skilled they could assemble things or do intricate things and then you'd put them to manufacturing, and the manufacturing operators couldn't do it, or they would get terrible yields for the operation. So, we always had to keep watching over their shoulders so that we didn't settle on something that was too hard to build for manufacturing.

**Warner:** I remember the 2305 actually went very smoothly. We had no big production problems with it. And I don't know if you remember Carmen Rosato was the Program Manager for the 2305. He was a tough guy, but he kept the whole program on schedule.

Miles Cook's team had moved out to San Jose from Poughkeepsie NY. We were making our own glass, making our own ferrite, and so forth. So we had it all set up in building 13. It was all done on the East Side (of building 13). There were the Ferrite Labs, the Glass Lab and the Ferrite maching labs.

**Carlson:** That was in Building 13? I thought it was on the East Side, but maybe it was not

**Warner:** Well, it got moved around, Bill, after you left. <laughs>

**Carlson:** All right, doesn't matter.

**Warner:** Anyway, after the 2305 I was assigned to the 3340 program. That's the Winchester.

**Carlson:** How long was the 2305 in production? I'm not familiar with that program.

**Warner:** I don't know how long it was in production. One of the things at that time, when you were a Technologist, you worked on the technology stuff. All the other machine group activities, (production) and that sort of thing we didn't pay any attention to, unfortunately. But anyway, so then the 3340 began, which was Winchester, or the 30-30, because it was going to be two modules of 30 megabits each. Ken Haughten was the Program Manager, and Chris Coolures was the engineering manager. I remember

  

Chris made a presentation to us. We were going to do this whole new concept, where the head would stay with the disk, and we would do start-stop in contact (the head would take off from the disk as the disk spun up and landed on the disk as the disk stopped spinning). The removable module would carry the heads around with the disk pack. This (heads staying with the disk) would allow us to get rid of a whole lot of tolerances and a whole lot of risk, as far as crashing. Well, it was quite novel in it's approach. It would also use a closed-loop servo. The 3330 used a closed-loop servo, and was the first one out of the IBM plant to do that.

**Carlson:** The 3330 was a predecessor of the 3340, and I know you worked on that as well.

**Warner:** Well, I actually did not do very much. I worked in the same lab area. Got involved some, but Dwight Brede had the 3330 Group, and Eric Solyst had the 2305 Group. And although we were next door neighbors, they did their thing and we did our thing. I mean, obviously there was lots of talking, but they were quite separate.

Going back to the 3340, we did something called the "We Program". The 2314 had all this contention going on between the Development guys and the Manufacturing guys, because Manufacturing said, "You gave us a product we can't make," and the Development guys said, "We did the best we could, and we're here to help you, and so forth." But there was a lot of animosity. And it had been that way for some time. So, Jack Harker came up with this concept, the "We Program", where we took a bunch of guys from Manufacturing, and a bunch of guys from the Development Lab (and put them together). There was an ACS, Advanced Computer System Lab up in Menlo Park that had just been closed down. They had a bunch of Process Engineers there, and we took our whole gang and moved to Menlo Park. And the idea was, the initial part of the program was going to be managed by Development. It meant initially a Development guy Ken Machado, who kind of oversaw the whole project. He had Eric Solyst working for him and he also had the Manufacturing people. And then later on, the management would transfer to Manufacturing and the Development people would go to Manufacturing to help on the program. So that was the "We Program" concept, which, by the way, I think turned out to work quite successfully. I was on the Winchester development part of the program, and I spent the last part of the Winchester Program, over a year, in manufacturing, working on the yields and how to improve things and any issues that would come up. We had eight development engineers there (in the Menlo Park facility) when we started out. The program was based on a tri-pad head, not tri-rail but three pads. Each pad had a little taper flat bearing on it and then the rear pad had a glassed-in core. The glassed-in core was something that had been developed by the 3330 team. They took a glass bonded ferrite core then used another glass that melted at a different (lower) temperature to hold the core in place in the head (this solved the epoxy problem). This method had been used on tri-pad head in a small file. When we looked at the work done and as we tried to make the heads it was obvious that would be almost impossible to make in volumes. The taper flat had to be generated on (the rear pad) a pad inside the head and there's no way to get at it. It was very difficult to get at. We tried all kinds of wild things. So I set out about looking at making another type of head, like a taper flat bearing but it wouldn't be a tri-pad. It would just be a two-rail head, and we would insert the core in the back end of the slider.

  

**Carlson:** Now, when you mentioned the tri-pad head, Al Shugart, in his talk, commented that it was a Data Disk design. I remember seeing the things in the lab, and is that the one you modeled or you're talking about?

**Warner**: Well, that's the one we started off with, and that's the one that proved to be, to us, unmanufacturable.

**Carlson**: Understood

**Warner**: I started to work on a design for a different slider air bearing, something that we could make. I used Tom Tang's air bearing program and I got on to the research computer to make the calculations**.** I think it was a 7090. I don't know for sure, but it was the biggest IBM computer going at the time, which was, I'm sure, much less than a PC or something today. The way you did your job was you typed up a bunch of punch cards, put them in as a batch job in the evening, and the operators would run the job overnight. Then, the next morning you'd go back in and you'd get your data point. Then, you punched some more cards, inserted them into the deck, ran it again. Then, you got another data point. Well, this was going to take forever. I mean one point a night, and you needed hundreds of points. So, I found a computer operator at the data center who would let me put jobs in whenever I wanted because my jobs didn't take a lot of time. They weren't accounting jobs or things like that. It was just short computational runs and then printing the results out. So, I then spent all night long, every night, making these runs. I would plot points, put another card in, do another run, and so on. If I would still have some data unplotted at the end of the night I'd bring it back to the lab in Menlo Park. I had a technician, Nick Nickels, who would plot the up data. What I found is a taper flat bearing like the 2305, which was a ½ inch wide head and had a conventional air bearing profile. But when you made the bearing very skinny the pressure built up in front of the taper like normal, but it (the pressure) would also bleed off towards the trailing edge. So on one rail it would look like it had a pressure spike in the front, dip down in the middle, and then it would have a pressure spike at the back or bottom trailing edge closest to the disk. This meant it was like a two-legged chair, so if I provided two rails it would have four peaks like a four-legged chair. So I discovered this phenomenon and started designing air bearings that would have four pressure points.

**Carlson:** Four points, makes sense.

**Warner**: Then I had to do the work of designing one for a machine. You need to have pitch stiffness and roll stiffness and vertical stiffness for compliance because the disk is fluttering up and down. The heads had to be able to follow that motion. We wanted to have the core at the trailing edge at the minimum spacing. So in this particular design, the head pivoted about the trailing edge which was very fortunate. I started doing all of the tolerance work, the width tolerances, the taper tolerances, how wide the slider should be, and I basically came up with a two-rail head design. As I thought about this more, I thought, you know "what if we used the 2305 or Zeus process where I could make a third rail in the middle between the two outer rails that would be narrow, whatever the read-write track width needed to be". The track width was like 3 or 4 mils, something like that, and that center rail was so narrow it would not contribute to the lift of the slider. So, I put that in my notebook and went back to Eric Solyst and said, "Here's a design for the head. It's using the process that we had used in the Zeus line." We knew how to index very accurately. We knew how to cup wheel grind. We knew how to do the lapping with the sine plates. We knew how to glass bond. We said because the head had to stay with the disk, cost was important. In the 2340 design they actually had two heads for each surface. The cost of the heads was very critical. The typical cost, even way back then, for a 2314 or such, I think was in the neighborhood of $15 to $20. Our target was to be less than $1. So we said, "This is the best chance we have" if it works. It's not going to take lines of girls. The only thing they have to do is wind a coil and terminate it and put the head on a suspension. We put a notch in the back so that we could clip the suspension in like we had done on the Zeus or 2305 product. This looked like a good way to go. Now, there were people who were working on the tri-pad head who were kind of married to that design, so it was a little bit of a problem. We had a few come-to-Jesus meetings about this process and I think they all saw we could make this much cheaper. A bunch of those people had not been familiar with the Zeus line and the "stiff finger" process and needed convincing. So, we actually got set up to do that, to make those heads, actually I think, down in the San Jose lab. We did the assembly and test work in Menlo Park.

There's a guy, Richard Wilkinson, who worked on the suspension. He was in the department so we worked together closely on the suspension and we made a suspension assembly with a welded on load-beam, and the load spring was part of the suspension. This became the familiar Winchester head suspension. Because we had four heads per arm, we wanted to be able to test each of the heads magnetically and then mount them to the arms. Because, if you mount the four head suspension assemblies to the arm and then you find one of them is bad, then you have to disassemble everything. Eric Solyst insisted on what's called a mounting plate for the head suspension. So, we designed a mounting plate that was then a testable unit that would then mount on the arms. George Pal came up with and worked out a way for swaging the mounting plate to the arm. We had an aluminum arm and a stainless-steel mounting plate and we had a little spud on the bottom of the mounting plate that was hollow so we could put a tool through the hole. Initially we just pushed a ball bearing through the hole and that spread out the stainless steel spud and pushed into the aluminum. The aluminum modulus (of elasticity) is much less stainless steel and so the stainless steel would yield as the ball was pushed through (the hole in the spud) and the aluminum would just be compressed and the aluminum would keep grabbing the expanded spud so it held it very tight. It's much quicker than screws or anything like that. Literally, you can secure it in seconds. I think at one time, on the manufacturing line, they automated it, so you just place the four mounting plates with their head suspension on the arm and run a tool (or ball bearing) through the hole in the mounting plates to secure them to the arms.

**Carlson:** Did you just use the ball once?

**Warner**: Yes. Well, later on they just had a plunger, just put a hardened plunger that went through, so that was a neat thing. One of the kind of the funny, interesting stories for me was the Machine Group wanted, because they had to put all these four heads inside (the disk pack) between the disks in this narrow space, a cam on the suspension. They could then put in a pickle fork, we called it, that would pull all the heads down, and allow them to put the arms between the disks. Then you pull the pickle fork out and the heads would release and lower onto the disk. So, we built the first head suspensions with a stamped load beam with a cam on one side and the gimbal suspension part attached to the head. We sent them down for testing in the machine group, and they sang like birds. They were terrible. There were resonances all over the place. We had a group under Ray AbuZayyad that was looking at head media interfaces and things like that. We did some tests where we put the head suspension flying on the disk then used a strobe light and then excited the suspensions at the same frequency as the strobe, so we could see all the motions. We just do a frequency sweep scan, so we can see all the resonant frequencies and see all the modes of vibration. Well, there's a mode where, because this cam was on one side of the suspension and not on the other, that the suspension was just moving all over the place.

**Carlson:** Due to the air pressure?

**Warner**: No. it's because you are accessing, just because you're vibrating it. A voice coil actuator is just like a shaker table, and so if you energize it at the right frequency and always when you're seeking different lengths there's someplace in there where you hit that component resonance. So, it would excite it and create the problem. Well, that's when I started to learn more about servo systems and what goes on. I had never before worked with a system that had a closed loop servo. My experience had always been with a detent so there's no feedback. Nothing feeds back to the hydraulic actuator or anything like that. The 3330 had that but it hadn't been necessarily a big problem that I knew about but in the 3340 it turned out to be an enormous problem. So we quickly redesigned the load beam so it was symmetrical, absolutely symmetrical. Before we had the wires run down one side of the suspension and the cam was on the other side. We now ran the wires down the middle of the load beam, and we put cams on both sides. So then while one cam would never be used, one would be used, and that solved the problem. As soon as we made it symmetrical it would function in the servo system.

Kind of related to that is another story. Hursley was making a 62 PC, I think it was, a file using eight-inch disks and a rotary actuator.

**Carlson:** Hursley is in England, right?

**Warner:** Yes, Hursley England labs. They were making files for low-end systems so power and heat and size were really important for them and cost was extremely important. So if they could pick up a Winchester low-cost head, then that was a big savings for them. Well, they put their first system together, and the rotary actuator had an arm with the head sticking out. So it's sort of like a linear motion, but it has some radial component to it because it's...

**Carlson:** Like an old-fashioned record player.

**Warner**: Yes, like an old-fashioned record player sort of, except that the head is mounted at right angles at the end of the arm in their particular case. There is some radial component as you access in and out. Well, they put the first ones together and they said, "Oh no, we're having terrible problems. Our servo system is unstable. Our Bode plots look terrible." So they said, "Can San Jose help us?" So, I was sent over there, that was my first trip to Hursley, and I looked at the oscilloscope, looked at the Bode plots, and said, "Would you guys disassemble the drive for me?" and they said "Sure," and the management and the engineers are all looking in there the clean room) and I go under the microscope. I said, "Does somebody have some nippers, some cutters?" and some technician ran and got them and I went in there and snipped off the two cams and they said, “You can’t do that.” I said, “Why not? I put them on. I can take them off,” and so we reassembled it and that solved the problem completely. So the Hursley product used the Winchester slider suspension with the cams cut off. The reason *wa*s while everything was symmetrical for a linear motion, when you went in a rotary motion the cams caused the whole suspension to roll or rock because it was not on the same plane because the cams hung down. So, lessons learned about servo systems.

**Carlson:** Yeah, when you exchange you have to watch out for the unintended consequences.

**Carlson:** Oh, you mentioned some synergies, the fact that the 3340 would not have worked had it not been for the super flat 3330 disk substrate.

**Warner**: Yes, that’s true. The tri-rail head, not tri-pad, meaning the two outside air bearing rails and the center rail that did the reading and writing would not have worked if we had had the older style disk. By having a disk that had been diamond turned, it was very, very flat. You can see if you have a tri-rail head and, if the disk is curved underneath, then that changes the spacing of the read/write element, located on the center rail, to the disk. So that was a fortuitous thing that happened. Otherwise, for this particular design, we would have had to insert a core in one of the rails and it would have cost a lot more.

**Carlson:** Just a side note for the audience-- what Mike is talking about is the original disk process used a brush polishing technique which left the disk, on a microscopic scale, kind of lumpy and so trying to fly over a lumpy surface is not too great. Germany came up with the idea, in Sindelfingen, of diamond turning the substrate, made it super flat and so without that technique, the 3340 would have had problems.

**Warner**: Because of the start/stop in contact we were now requiring that the head and the disk meet each other intentionally. Before, they would meet unintentionally when you were loading and unloading. We started up a group called, for lack of a better term, I don’t know if they had another title, Mechanical Integrity. The group was looking at wear and lubricants, the tribology, study of lubricants on surfaces. They did a lot of instrumentation work. They did things. for example, like making glide height sliders with piezoelectric crystals on them so that if they hit an asperity the piezoelectric crystal would vibrate and give it a output signal. The guys in that group were managed by Ray Abuzayad. I remember Gene Zierdt, I think he worked on these, worked on heads that would actually mow down asperities, any of the little things sitting on top of the disk, The sliders would clip it and mow it down and that’ll become important when I talk in a few minutes. There were guys like Chu Lin and Bob Sullivan and Murray Hill, a bunch of really talented guys in that group who supported the technology. While we were doing the actual designing and developing and testing, they were doing an overall bigger test. They also took over the air bearing program, not necessarily the design of the air bearing because we would design with that program. We’d use their tools. Then there was another group called the Channel Integration and the Channel Integration group was taking the heads and the media and the read/write channel and putting those together and testing them. They were helping us sort out the tolerances for the heads and disks. Their tool was a spindle in an enormous great big granite block that was used as a test stand. They cut a hole in the floor so that it was isolated from the building, so it wasn’t attached to the building. It had a big spherical, I think 9 inch or larger graphite carbon air bearing with a fraction of a micro-inch runout or something like that. The heads were positioned on air bearing slides with laser interferometer controls so they could position extremely accurately a head over a disk track and they would then do tests on how capable was the head media to tolerate off track. Now remember, the other heads that I talked about had the old style of write-wide/read-narrow and erased the side tracks. Well, in this case, with the Winchester technology, there was no side erase. You just wrote, so you had to position accurately enough to stay within that range of tolerances to read back accurately. Now, when you look at all the tolerances: servo tolerances, thermal tolerances, tilts, head-width tolerances, disk flutter, everything that created some sort of misregistration were all evaluated by that group. Then what we would do is kind of divvy up who got what share of the allowable tolerance. We got this much for the head width tolerance. The disk got this much for their tolerances. The servo got that much, and so it was a very important activity. The guys that I mostly worked with at that time it would be, Jack Swartz from the channel, and Jack Grogan and Andy Gaudet and guys like that who were involved with channel integration. So IBM was investing an enormous amount of money in setting the groundwork and the basis for technology something that small companies could never do, As a result of this, when we came out making heads with these kinds of tolerances, we knew that they would work and when other companies on the outside used Winchesters they would use similar designs.

**Carlson:** How long did it take to prove out a design?

**Warner**: It would take years. They tested 24 hours a day. There were tests going on at the same time with start-stop testing and lubricant testing and things like that. That testing went on with components before it ever went into the machine. Machines would go to the Product Test for further testing. It’s a scenario that lots of people might not know about.

**Carlson:** I didn’t know about that. Well, you mentioned lubricants a couple times. Was the Winchester disk lubricated?

**Warner**: Yes. It had to be lubricated because of the start-stop in contact.

**Carlson:** That’s probably the first IBM disk product that was lubricated.

**Warner**: I think the little project that had been done before with the tri-pad head had been lubricated. There were people like Dr. Franke Talke from Research who were involved with lubricants. Ray AbuZayyad’s group was involved. There were a bunch of people that were involved, and the lubricant was super-secret. Lubricants were never even shipped to the San Jose site. They were shipped to another plant and then to another plant and then into San Jose. They did everything they could to hide what lubricant was used. I didn’t have a need to know, so I never knew.

**Carlson:** Well, there was something new by Dupont called Krytox,.

**Warner**: There were a number of lubricants at different times, and the problems with the lubricants, one, they had to stay there for years on a spinning disk. It turns out that the head is a very good collector. It’s pushing along, and it has this beveled surface in the front, and it'll collect any kind of dirt and crud or whatever else that goes on the disk. It also tended to push up lubricant and then create an unlubricated surface beneath the head. And, as you know, there're particles in the disk coating that were also helping the wear and those had to be controlled. There was a lot of technology in making the start stop in contact work.

**Carlson:** Amazing amount of diverse technology.

**Warner**: Yes, right. By the way, that's part of what made, I think, the disk drive industry so interesting for somebody like myself.

**Carlson:** Me, too.

**Warner**: There were all kinds of materials stuff that was involved. All kinds of process stuff that was going on. There's ceramics, there's casting, there's flex cables there's thermosonic bonding to learn. There's all manner of things, finite element analysis, air bearing analysis to learn. It was great.

**Carlson:** In those days, we didn't have PCs, so everything had to be run on big computers.

**Warner**: When we were doing the x-bar and R charts and all that stuff, well, we would plot the data from Frieden hand crank calculators. We'd put the data in by hand so that's how it was in the beginning. And in all the meeting minutes we'd write them by hand, and then give them to the secretary. She'd type them up on a mimeograph, and that was in the 2311 time. For the 2314, we had Xerox machines. That was the big advance.

**Carlson:** Oh, I remember the building 25 research lab had one of the first Xerox 914 copiers. It had a fire extinguisher right beside it due to the risk of catching fire.

**Warner**: There was a really rich cast of characters on the 3340. I think I mentioned Dr. Ken Houghten and Cris Coolures. Dick Mulvaney, a very creative guy, who worked with Rudy Lissner on kind of basic module design along with, Shel Ellis and, Dr. Jim Lucke. Bob Freisen was the servo manager, I think Dr. Dick Oswald was the initial designer of the servo system. and Jim Gilmore was an engineering manager, so there were a lot of good guys that were working on the machine. Remember, there are casts of hundreds, there are a lot of engineers each doing his piece.

One of the problem areas we had as a result of the taper flat bearing and start-stop and contact is we had a thing called stiction.

**Carlson:** Yes.

**Warner**: It was probably, I think, the biggest single problem that the program experienced. This was an open-loop airflow. so it collected air from the outside, went through a filter, and around, kind of supposedly sweeping the disk clean.  But it turned out that there was a washing process that was used in the disk line that left some contaminants.  The contaminants would combine with the lube and after a while and it would make kind of a sticky stuff that was angstroms thick probably.  Not thick but we have very flat heads and the heads would stick to the disk.  And because we had to have a rapid spin-up for starting and stopping in contact, you couldn't drag the head a long way or it would wear. So we spun very quickly so we had a big motor. So, the big motor, every once in a while, would just rip all the stuck heads off the suspensions.  So, we go examine and find there would be a few heads around the outside casing and a bunch stuck to the disks.  It would just tear the suspensions off.  Stiction was a problem for every taper flat bearing product we had.  The issue was if you could keep control of the environment, then you were great, but if you had any kind of contaminants that got in that you didn't know about, either introduced in the manufacturing process or somehow got in from the outside environment, then it could collect because the head, as I say, was a really good collector and the taper would scoop up stuff.

**Carlson:** So how did you fix this problem?

**Warner**: Well, initially it was one of changing the cleaning process.  We got rid of whatever it was that left a residue, and then in general, keeping things very clean and well-filtered so that we could actually let the head media interface work as designed.

**Carlson:** I know with the 3330 we had to use HEPA filters because the aerosol, greasy stuff in the air from jet planes and cars would get in...

**Warner**: Yes, absolutely.  That's why we used HEPA filters on the 3340.

**Carlson:** The 3330 was the first use of HEPA filters.

**Warner**:  And there's another incident, I think with the 3350 or one of the products. We wound up with a problem from the material that they put in cooling towers for air conditioning in the big glass buildings where they had disk drives. I mean where they put disk storage. Sometimes there's a material they use to keep the fungus from growing in the cooling tower water because it would smell musty.  Because the cooling tower makes these very, very tiny droplets, this material that was a fungicide would get in the air and that would find its way through the filters and collect on the disks and create crashes.

**Carlson:**  We saw that problem on the 2311 drives at the airport. The heads were collecting a bunch of junk, and it turned out it was aerosols and the HEPA filter solved that.

**Warner**: Solved it.

**Carlson:** So next, you had the 3350. You worked on that.

**Warner**: A note about 3340. I personally saw Winchester type head manufacturing lines in Germany, Bulgaria, Japan, China, and at least three companies in the U.S.

  

**Carlson:** Oh wow, all doing that.

**Warner**: All doing that, and at one time we almost were going to cancel the program because we were only going to make 700,000 heads. That was during the business planning cycle. Ultimately, Winchester heads were made in millions per day around the world.

**Carlson:** It's amazing.

**Warner**: So anyway, just to blow my own horn, I got an Outstanding Invention Award for the Winchester head and some cash and a trip to New York, which my wife appreciated to make up for some of the long hours.

**Carlson:** As I mentioned, Al Shugart thinks that's one of the four greatest inventions in disk drives.

**Warner**: Well, good.

**Carlson:** Okay. Anything else on the 3340?

**Warner**: No.

**Carlson:** That was your baby.

**Warner**: That was probably where-- on that program, I still worked as an engineer and I worked as a manager and obviously started learning about IBM. IBM is very good at training you. When you become a manager, they send you through lots of classes to learn initial management.

The 3350, from a machine standpoint, was a major departure because it no longer had moveable packs. It had now fixed disk stacks.

**Carlson:** A fixed disk machine.

**Warner:** It was fixed. It had a taller stack. But from a head standpoint it was a narrow track. We just changed the program on the stiff finger line. So, as it indexed over, it indexed a little bit different on that center rail. And also the read-write gap changed. Now, I think I failed to mention that the read-write gaps in the 2311 heads were formed by putting a copper or brass shim in the gap and you closed the mumetal structure by squeezing it closed and ball staked it into the slider. In the 2314, the gap was formed by glass, and when they took ferrite bars and put them together, they actually used platinum shims, because platinum wouldn't be dissolved by glass. The platinum shims were placed on either side of the ferrite bar while pushing the ferrite together and then the glass would flow in the gap around the shims. On the Zeus (2305) program, we did a thing where we actually deposited material, a glass material, on the surface before the two ferrite halves were put together. It was done in a vapor deposition machine and so it was done extremely accurately. One of the manufacturing guys came up with a very clever way to do this. As the shim material was deposited where we wanted in the head structure it also deposited on a sheet in the chamber that had an interferometer looking at it. Thus, it could measure to a fraction of a micro-inch looking for the interference fringes as it deposited. When it got to the right thickness it shut the machine off. So, when we changed it to the 3340 all we did was change the setting on the equipment.

**Carlson:** So that's the synergy you were talking about. From one program to the next, you keep using or keep improving the technology.

**Warner**: Yes, and so we had all sorts of plans. I don't know whether they were ever completely implemented in San Jose, but on the Winchester virtually every step of the way there were plans for complete automation. It could have been done. Later on, I learned something as far as how the Japanese do their automation. They set up a line, a manual line, and then they choose one step and then they make a machine for performing that step. So, there'll be girls putting stuff together, which goes into a machine, then on to more girls putting stuff together, and they're almost always ladies because it's very fine, tedious work. Then they would put together another machine and then another machine and then pretty soon all the machines are working together. So, they do it one step at a time. That seems to be the way they do automation. So I think the 3350, from a technology standpoint, from our manufacturing standpoint, was virtually nothing in comparison.

**Carlson:** Basically, it was a dedicated Winchester type of design?

**Warner**: It was a dedicated Winchester.

**Carlson:** But the capacities were taking big jumps.

**Warner**: Capacities were taking big jumps. Performance was taking a big jump. The machine looked quite different, but the technology, the heads, media, so forth, as I told you, required just a couple changes to the heads, probably some minor changes to the media and read write channel. They may have flown a little closer or something like that, although I don't even think that.

Now, the next one to ship was the 3370 program and it was the first program to ship with thin-film heads. The 3370 had been kind of stuck in at the last minute. The 3370 was for the midrange systems, and it basically used 3380 technology which would ship later. It used the thin-film heads, thin-film head suspensions and oxide disks. So from a development point of view, it was minimal work. I forgot one other thing that happened on the 3350 program. We had a diode selection matrix module mounted on the arm for 3340, and in that module they put the pre-amp and the diode selection modules for the 3350. We then used a polyimide flex cable that went out from the arm out to the read/write channel. That was a change from the leads and the springs and so forth used on the 3340.

**Carlson:** To get the electronics closer to the head?

**Warner**: Electronics were closer to the head because the tracks were narrower and we would have lower signal levels. This improved the signal-to-noise by having the pre-amplifier closer to the head.

**Carlson:** What was the timeframe of the 3370? That's kind of not on most people's radar.

**Warner**: It would have been a couple years before the 3380 (1979). The head line was up, and working. We had suspensions and heads and so forth, but by using the oxide disks and using the previous level components it turned out to be, from a technology standpoint, not a big significant program (because it used mostly 3380 technology). I think Al Rizzi was the 3370 machine program manager and Jim Makiyama was one of the key players for that program.

**Carlson:** Where were the film heads made for that one?

**Warner**: They were all made in San Jose.

**Carlson:** Okay.

**Warner**: They came right off of the 3380 line, slightly different dimensions. The 3380 was an enormous program. I think it was probably, or became, the largest disk drive program IBM ever had. I remember one of our planning/marketing guys saying it would be the largest industrial program in the United States ever.

**Carlson:** Really?

**Warner**: It was bigger than Boeing, bigger than whatever. It was destined to be a very major program. I joined it after I finished with the 3340 and spent a year in 3340 manufacturing. I went for a short time to an inkjet printer program but I was pulled in to work on the 3380 and it had just been redefined. It had been, I think, a great big disk, horizontal, and people said they were starting to understand the significance of space and power. There were all these big rooms in New York City full of disk drives and they needed more storage, and they didn't have any more room. They couldn't build new buildings, so having higher storage density per square foot was almost as important as having higher density per square inch as far as recording density. Anyway, to make a long story short, we started off on a long process. I worked for years and years on the 3380. The initial design work for the thin film heads and suspensions and so forth was done relatively early on and didn't change much at all. The real problem was the head-media interface. There's a whole lot of technical stuff that goes on regarding the read - write channel. They had to change the encoding and decoding scheme and a whole bunch of other things which I won't go into. They're covered in other oral histories.

But I will say that the thin film heads were made in a batch process. There was a substrate a couple inches square with deposited thin film elements on it. Well, if you make a great big slider, then you can't make~~,~~ very many sliders out of this two-inch square substrate. So, there was a lot of pressure to make the heads smaller so we could get a better yield or number of heads out of these thin film substrates.

**Carlson:** Wafer substrates?

**Warner**: We called them wafer substrates, and the substrate was going to get sliced up so that the thin film element resided on the back end of the head. We would use a tapered flat bearing on the head or slider. The design work was initially to select a slider size, and the slider had to be big enough that it would offer enough roll stiffness and pitch stiffness and vertical compliance. We had to design a suspension to match the slider. Suspension designs, by the way, are very interesting, because you are having very high g acceleration levels while you're accessing, and sometimes you hit crash stops, which put way heavy loads on them. They had to be very compliant to let the head pitch and roll but also it had to be extremely stiff in the accessing plane. It can't move x *and* y directions, but they had to be able to move really well in the z direction. It had to have low pitch and roll stiffness. So, matching the suspension and the air-bearing stiffness is somewhat of an involved piece of work, and I had guys working for me on those design problems. Bob Watrous was working in the suspension and Mike Garnier on the air bearing, and Norm Frater was doing the finite element modeling. I think I must've explained, making things very symmetrical was important for high-performance servo systems. So, this suspension was a skinny triangular design. A triangular shape is far and away the best shape to make a suspension assembly, with a little gimbal portion on the head end, and then the spring providing the load for the unit. On the Winchester, a guy by the name of Richard Kurth developed a technique for setting the head load on the disk. We used to bend the springs and, you know, if you bend a piece of metal, it'll creep back a little bit, so the load would change. Richard was a metallurgist, so he came up with the technique of heating the spring to adjust the load. He would form it, over form it, and then heat it with a laser to slowly bring the load into specification, and it then became very stable.

**Carlson:** Is that a dynamic or one-time adjustment?

**Warner**: Just one time. We set it in the factory using a mounting plate.

**Carlson:** That prompts an interesting question. A lot of our viewers and listeners might be interested in some of the materials involved. You mentioned we went from stainless steel sliders and ball staking to ceramic and epoxy and ferrite, and then I believe 3370 was carbide.

**Warner**: You're just going to steal my thunder, Bill. That's exactly where I'm headed. <laughs>

**Carlson:** Okay.

**Warner**: So anyway. we made this much a smaller slider, and I don't remember what, initially the material was that we designed, but we were having problems in particular with the film disks. The mechanical integration group was doing the burnish heads. They were doing glide height testing heads and things like that, and they were also measuring dynamic compliance, which they did with capacitance probes. But you can also do that directly if you have a conductive slider. Then you can look at the change in capacitance as the head is flying. So, they used a material that was actually a electrically conductive tool bit material. It was titanium carbide and aluminum oxide mix, in 60/40 or something like that percentage. It was an extremely hard material. It could be made very flat, very dimensionally stable. We were also having this head wear problem. I think it was Chu Lin who suggested, "Why don't we try this N-58 material?". Well, we looked at it, tried it, and it worked. It was a very short examination time, because they had had a lot of experience with it. We adopted this material, because it wore very well. Previously the heads were wearing out, I mean, the disks were wearing out the heads due to abrasion during start stop in contact. With the new head material if it hit the surface hard enough it would wear out the disk. This material also had a very high modulus so we could make the slider thin so we didn't have to cut a notch in the back to mount in the suspension. Because we could now make a very thin slider, we could make many of these little tiny sliders per wafer and get a good yield. This all kind of worked together. Make a smaller, harder and stiffer slider. There's less mass being moved around so that you get away with not having to put the push point at exactly the center of mass of the slider. We made the wires come straight down the center of the beam to the mounting plate. We elected to use a mounting plate and because we had a thin aluminum arm (that did not lend itself to swaging like the 3340) and we elected to put screws in for attachment. I think we should've worked harder not to have the screws, but we used screws to mount the head/suspension on the arm. These arms for the 3380 had four heads per arm the same as 3370 and same for the Winchester. This assembly went into a very high-performance servo system in which the coil was part of the moving mass and the coil had no bobbin. The whole system became very sensitive to any resonances. This was quite ~~a~~ good performing head suspension assembly for servos and became adopted by the industry for thin film heads. Again, channel integration was a major piece of the puzzle. We spent literally years optimizing the thin film head. The thin film head work was started in Yorktown and transferred to San Jose. Ian Croll managed the whole film head team with Dr. Bob Jones. I worked for Ty Cowen, and he, pretty much let us do the head suspension, assembly, all that sort of work, and he focused on working with the thin film line and the disk guys and working at kind of understanding and trying to make that whole system work. Now, we never did make a metallic film disk work that got through product test for the 3380. We used a thicker disk as we were trying to reduce the flutter, and we knew we wanted to have a family of products that went on beyond the 3380. So, in the end, literally, not before we announced, but in the end we made a switch to an oxide coated disk, and that was really because of some underground work that Jack Grogan and Andy Gaudet did and then said, "Hey, we could make it with oxide, and we could meet the magnetic performance and still have a reliable product."

One other thing to mention about the tiny thin film heads. Attaching wires to the heads looked like it was going to be a challenge but, remember, we had members of our team who had been part of the IBM Advanced Computing System at Menlo Park. They had done a lot of work with ultrasonic wire bonding, and so they had a technique of having a copper wire that was gold plated on the outside and could work with ultrasonic bonding to the gold plated pads on the head. So that's the technique we used to attach the wires on the heads. We actually could do ultra sonic bonding to the flex cable, although I think they used soldering for a lot of the wire termination (on the arm).

**Carlson:** That's something we did in Tessera, the gold bonding.

**Warner**: These little bits and pieces of technology that were developed other places were kind of all brought together. One of the key things with this bonding process is, as the bonder tool comes down, it does a bond and comes away. It always keeps control of the wire, so it can be done automatically. So, you don't have to go fish for the wire.

After the 3380 Program, I was asked to do a tour of duty on the EP&T staff. That's Engineering, Programming and Technology, and I worked for Bob Evans. That job was one of going around to all the

IBM labs and reviewing their plans. IBM did two plans, a spring plan and a fall plan. The labs would say, "Here's how much money we want to spend, here's how many people we're going to hire, and here's what we're going to work on. These are our product goals, this is our technology," et cetera. Then, you know, the high-price help in Armonk didn't have any idea what these plans were all about.

**Carlson:** <laughs>

**Warner**: They didn't know whether to give them the money or not. So, they had a trusted guy in Bob Evans, who had a staff who went around and evaluated the plans. Bob selected technical people from within the organizations and we went around and reviewed what was going on, and then make comments. For example, in some cases there might be five labs working on optical recording. When you say, "Well, the five labs are working on optical recording and each lab has a few people. There's no critical mass. So what we should do is put a critical mass and move all the work to one of the labs". We would usually recommend a lab. We would say the other guys should stop spending money on it, and that kind of thing. So that was our goal. We were kind of the black-hat bad guys flying in from corporate. Of course, one of the reasons you get sent back to do that job is that it gives you a chance to see what the rest of the company is like, that you get to see other labs. You get to meet lots of other people. You, kind of get around. That was supposed to be a two-year assignment but I didn't last for the two years. I came back to San Jose and became the DASD product manager after one year, which I'll talk about in a minute.

But there's one story I think is kind of an interesting. The corporation was concerned about "How are the Japanese doing?" We were worried that they were going to take a lot of business from us. So we wanted to understand what their capabilities were. We arranged, with IBM Japan, to have exchange visits with Fujitsu , NEC, Hitachi, and TDK. We formed a visiting group made up of Jack Harker, Denis Mee, Lew Taft and myself, plus another guy who was involved with the tape products. So, we went to Japan to go visit these companies. Dr. Lew Taft had been on assignment in Japan because he transferred a tape process from Sony to the IBM Boulder plant. He knew his way around Japan. So, the first night he takes us out and teaches us how to be Japanese. He taught us all the rules and the protocols and what to do and, how to do things so that we didn't stick out like sore thumbs. Fortunately, he did that because the next day we went down to the South Island and visited TDK. We got there at the end of the day. By the way, we were always accompanied by an IBM Japanese guy and we were also usually accompanied by guys from companies we were visiting. We went out that first night to dinner. They took us to a restaurant, and we had two servings in front of us, one American or Western food, and another, Japanese food. Well, Lew had told us, you know, "Be sure and eat the Japanese food." So, we ate the Japanese food. The next day we visited, TDK and did our work. By the way, I saw their automatic line for making Winchester sliders. At that time, we brought the book I just showed you about the 3370, right here ("Disk Storage Technology" IBM 1980), which had thin film heads and so forth. We brought that book along and the Japanese said that was the best Christmas present they'd ever gotten.

**Carlson:** <laughs>

  

**Warner**: The book showed them what we were doing and how we were doing it and so forth. That night, we went to the city, which I don't remember which city it was, and we went down this little alley to go to dinner and it looked like we were going to get mugged or something. But we went into this place, and there we had a tea ceremony, a very elegant tea ceremony, and then we went into another room to eat. There were the six of us, plus six of the TDK people. So, we were one side of the table, they were the other side of the table. There were service ladies dressed in kimonos and big hairdos one for each one of us.

**Carlson:** Oh yes, been there & done that.

**Warner**: So, they poured our drinks for us and prepared any food that had to be prepared at the table. We had a waitress, so to speak, for every individual, and it was course after course after course of all different kinds of stuff that I'd never even seen before. But it was one of the most elegant dining experiences I ever had in my life and it was very memorable.

Anyway, the result of that whole visit was we learned that Japan had a government organization that it called MITI.

**Carlson:** MITI, yes

**Warner**: MITI (a Japanese government agency) was coordinating the technology efforts between NEC, Hitachi and Fujitsu. So one company would work on plated disks. One company would work on sputtered thin film disks. One company would work on particulate disks. One company would work on this or that kind of thing. Then they shared their knowledge, and they also made a common disk file where they could test the results of their work. The Japanese government played a big role in orchestrating technologies. That's how they were keeping up with IBM by having this coordinated effort between the many companies.

After coming back to, San Jose, I took on the role of a product manager. The product manager in IBM at that time had the planning and the revenue responsibilities for the high-end disk DASI (Direct Access Storage Device) products that were made in the division. It included something like 650 to 750 engineers and other support people in that organization. So I had a big team of people and a whole new responsibility. Quite frankly, I was not very well prepared for the job. I had never been in a customer's office as an IBM employee. I'd never met with a customer, and yet in this job, one of the first things that I had to do was go talk about problems with customers. They had this problem or that problem and I had to go talk with them and tell them what we were going to do and how we were going to make it all better. I'm sure I must've made some really poor impressions on people because in some cases they were talking about control units that I didn't know anything about. I'm a relatively fast study, but still I was thrown in over my head. There were guys like Dick Whitney who, if he hadn't have been there I would've been completely lost, because the whole product planning process was one that I wasn't familiar with. At this time, I think the revenue from the disk drives was running over five billion dollars per year.

**Carlson:** Oh, huge.

  

**Warner**: -- That's an enormous amount of money, and I was supposed to have the profit and loss responsibility for that. Well, the truth is that's way too much money for anybody. I had lots and lots of corporate help and division help, and as a matter of fact, I could hardly do anything. I mean, everything was dictated. Our division president, Jack Bertram, ran weekly meetings on everything, on customer satisfaction, yields and et cetera. So, it was a job where you were given the responsibility but you weren't given total authority

**Carlson:** Yeah, I was going to ask the question, if you had a ticked off customer, what was your authority to solve his problem?

**Warner**: Well, it was probably pretty reasonable. I mean, I could do some reasonable actions but mostly everything was in the works anyway. I mean, I wasn't actually saying, "We're going to do this. We're going to do that," as much as I was conveying to them as a IBM executive, "We care about you." So we did that.

But one of the things that I kind of looked forward to is that in this job I was supposed to do the planning for the next generations of products. We had in the works, right then, I think, a 3390 that had been kind of sketched out and it was going to be an 11-inch disk or thereabouts. I ran a task force for over a year and we met every week. I had the best minds we had in the area, and we looked at, "What kind of products should we be making?" "How could we make the systems perform better?" We had systems performance analysis by Currie Munce and his guys. There were guys like Jack Grogan and guy by the name of Jim Gilmer who worked on staff for me. I think it was probably the most frustrating year of his life.

**Carlson:** <laughs>

**Warner**: Because, I mean, he worked on this stuff and none of it got to see the light of day. I mean, we weren't designing products, we were designing what were to be the specifications for products, what kind of family of products were needed. Everywhere from large capacity to moderate capacity to really high, 16,000 RPM disks, for example were examined, what kind of stuff should be considered and what our modeling said would work. When I tried to present the product plan to the corporation, it didn't fly. I couldn't sell it and I blamed myself for not being not smart enough, understanding enough, whatever it was.

**Carlson:** What were the objections? It was too costly or complex?

**Warner**: One of the objections was, we have a whole big bunch of buildings full of equipment making 14-inch disks, in which we had a big investment. Our product plans included improving the 3380 and making, you know, higher capacity drives. But the 3380 didn't do a lot of things. It was a fantastic product. It made billions of dollars for the corporation. The product family ran for 12 years or something like that. But the question was "What are you going to do next?" I was convinced from the work we had done that making arrays of inexpensive drives was the way to go. A 3380, depending on its configuration, cost around $120,000 and that was for two and a half gigabytes.  Two and a half gigabytes. I mean, that's just nothing now.

**Carlson:** By today's standards, yes

**Warner**:  The 3380 was a very complex drive to build, a very expensive drive to build, and companies on the outside were making, with IBM technology, small form factor drives for a fraction of our costs.   I think we had a Computer History Museum session and Jim Lucke had a (spindle) bearing cost comment.  I said, "Well, Micropolis made the whole drive, castings, motors, actuator, the whole thing, for the cost of that bearing."  I mean, there was just no comparison, and I thought that IBM was going down the wrong track.

**Carlson:** Well, now, Hursley had made a small form factor drive--eight-inch or something.

**Warner:** Yes, but there are complications to all this stuff that I'm talking about, having to do with the count key data versus fixed-block architecture, which I'm not going to get into here. But we had boxed ourselves in with count key data formats that limited a lot of stuff that we could do.  Probably out of this, if I am going to tell a story, it is that we were going to do an enhancement to the 3380, and we wanted to do a double density version.  We'd been having problems with stiction and other things and so we got the team together and went down to Carmel.  We had 50 or 60 people down there, including the head guys, the disk guys, the channel guys, everybody.  We asked, "Can you do your part of making this product?" Each group basically said, "Well, I might be able to do my part, but I don't think the other guys can do their part."

**Carlson**: <laughs>

**Warner:** And so it was, we spent two days talking and planning and we agreed to go back and get to work.  I agreed to go back and present one and a half times drive capacity, which I knew people were not going to be happy with.  They wanted it two times capacity.  But we agreed that we would meet sometime later to review our progress.  People went in earnest and looked at what they could do to do their part of the job.  Four or six months later, we met and we agreed to do the two times 3380 capacity.  But it's one of those cases where guys had all felt beat up, and they didn't want to commit to something they weren't sure they could make because they knew what would happen if they didn't.  So, here's a case of giving them some time to work while holding the powers to be at bay for a few months.  We then came up with a new program.  That's probably one of the highlights of that period of time.  I became so frustrated with where we were going that I decided that I was going to leave the company.  I said, "I don't think we're going in the right direction, so I'm going to go do something else".   If you remember, Bill, most of the head hunters had organization charts for IBM and they were calling all the time.

**Carlson**: Oh, yes.

  

**Warner:** I always said, "No, no. I'm not interested." A Couple of times I talked with people more than just hanging up the phone. But at this time I was ready to go. So somebody approached me about taking an engineering job as a VP of Engineering at Micropolis and I listened.

**Carlson:** Before we leave IBM, how would the culture change over the-- you were there 20 years, so you have a long history there.

**Warner**: You know, it's interesting. The San Jose culture didn't change so much. It changed a bit when Jack Bertram came, because he brought some East Coast culture. When I went on EPT staff, I found that the East Coast IBM was very different from the West Coast IBM.

**Carlson:** In what way?

**Warner**: In that, the East Coast people had their way of speaking. It is more confrontational, they shoot barbs at each other. They were more protective of their territory. In the San Jose world, remember, we had a "We program", where we worked together, and in the East, I don't think they would never have had a "We program". There was much, much more cooperation in San Jose. We had guys like Ken Haughton, Jack Harker and Denis Mee and guys like that who were managers and leaders, although Jerry Harries was pretty confrontational. But we had people that led by example so we lived a different life. We didn't live in fear of our jobs or whatever.

**Carlson:** So as you moved up in the ranks of IBM, I guess it became more Eastern oriented and more confrontational?

**Warner**: -Yes, there was more of that. But I think IBM San Jose was still a very good place.

**Carlson:** Oh, beautiful place, but anyway, a headhunter got ~~a~~ hold of you and you took the job.

**Warner**: I took the job at Micropolis, and by the way, I loved the job. They were making a half-high five and a quarter inch drive that was very successful.

**Warner**: They were selling to DEC and to other companies. I worked for Stu Mabon, who was the president and Eric Dunstan, who was also one of the founders. He (Eric) was kind of technical guru at large. Very, very smart guy who knew everything about everything, and, I mean, seriously.

**Carlson:** I think I met him once.

**Warner**: He's a very good guy, and Stu was also. Ed Hecox was there. He had joined from IBM as a manufacturing VP for Micropolis. Stu wanted to make some more products, but he didn't have a full engineering staff. He had, I think, 35 people in his engineering team. Now, remember, IBM did machines with hundreds of people. Micropolis's total engineering staff was like 35. One of my jobs was to help define the next products, but Stu was quite good at that. He knew what he needed for the marketplace, and I was to go and hire people to design the products. In the relatively short time I was at Micropolis, a year and a half or so, I hired and took the engineering staff to over a hundred engineers. I personally was actively involved in a lot of the hires. I took the special ones out to dinner and talked with them about the company and southern California. Part of that was so that there wasn't as much burden on the guys who were doing the work. Obviously if somebody's going to join this guy's organization or not, they talk with him and they did that. I also liked that I was part of everything. I was there at the board meetings, and at the executive staff meetings. We went to trade shows. I met with customers. I went on sales calls, and when I look back I say, "How could I get all that stuff done in that time?" but it was fun. I was very busy, and I cared a lot about it. Now, their approach at Micropolis was to use vendor technology for heads, media, chips, and then internally they would design the castings, the actuators, the motors, the PC boards, so forth. They designed disk drives but they did not do any of the, quote, "technology work." That was purchased from the outside. So we bought chips for rewrite channels, chips for the SCSI interface, chips for everything. We bought heads and disks to our specs.

**Carlson:** In those days (1985) a lot of industry had grown up. I remember AMC and various people were making these parts.

**Warner**: Yes, Infomag and other companies were making heads. All the disk makers were going on strong, right.?

**Carlson:** There were several doing so.

**Warner**: I probably would've stayed at Micropolis but two things happened. Jim McCoy of Maxtor somehow decided that he wanted me to work for him. I had worked with Jim at IBM and he knew me personally. I also had a house in San Jose that hadn't sold, and I was making terrible double house payments. So Jim offered me a way out of my financial situation, I think I mentioned Jack Swartz. Jack Swartz was one of the founders of Maxtor, and Jack had been the Engineering VP. Jack didn't want to continue in that job and was in favor of my coming. It was smooth from that standpoint, so Jack was going to work on the side and do some advanced tech work and things like that. I joined Maxtor, and there was a good team of people, a stronger management team (than Micropolis). There was Bill Dobbin for Financial and Steve Kitrosser for Manufacturing, Bob Teel and Leon Malmud in Sales/Marketing. We worked very well together. Jim is a good team leader, and visionary. So, I set about defining some new products and then hiring people. The same thing. I hired well over a hundred people in all, probably closer to 200 people into Maxtor. In many of those hires took I took them to dinner. I mean, I hired you Bill, right? <laughs>

**Carlson:** Yeah, you sure did.

**Warner**: And Ron Dennison and...

**Carlson:** Jack Osborne

**Warner**: Yes, Jack Osborne and a bunch of really good guys.

**Carlson:** Really good people.

**Warner**: We had a good solid team of people at Maxtor. We continued to increase the capacities of the drives. They were in production making full high five and a quarter eight-disk stacks and we increased the capacity of that drive. We did a 3 1/2-inch drive, I think a 2 1/2-inch drive, a number of products for the company. Then one of the people I hired tried to shoot me down, and he succeeded. <laughs>

**Carlson:** Uh-oh.

**Warner**: And so I was terminated from Maxtor by the relatively new president we had brought to run the company. Jim thought the company was growing so much that he wanted to have a more professional manager come in, and we did. And then, I was terminated.

**Carlson:** Who took over?

**Warner**: You mean afterwards?

**Carlson:** Yes.

**Warner**: --I don't know who took over my job.

**Carlson:** Well, one of the questions I had was how did the relationship go with you and Jack? Here's the founder, who now works for a newcomer. Very creative guy. He was pushing glass disks and film heads.

**Warner**: We got along great. Absolutely great.

**Carlson:** I thought you did.

**Warner**: We were friends at IBM.

**Carlson:** Jack was IBM as well?

**Warner**: Jack came from IBM. He was the guy who got the preamp and diode matrix module put on the 3350 and 3370. head arms.

**Carlson:** I Didn't know that.

**Warner**: He's a good engineer, and Jack and I actually had, at one time, talked about going out and starting a company. So, we were that kind of friends. <laughs> Anyway, that part went quite well. I don't know if you remember, Bill, I introduced a matrix organization.

**Carlson:** Yes, I knew that.

  

**Warner**: And the reason for that was because as we were growing we weren't hiring enough people to balance between programs. We had a product team making a three and a half, another product team doing high capacity, full high drive, another team doing something else, and we only had a few experts in rewrite channels and a few experts in other fields. So by having the matrix we could assign people to programs as needed to support all those programs as needed. I think it probably was just semi successful. We went from people who were used to being dedicated on a product and then needing to share time was a problem. Some people worked well with it. I think you were one of the guys who worked well with it. I think you were responsible--

**Carlson:** Yeah, worked well.

**Warner**: --for heads and media and so forth.

**Carlson:** Well, actually, at that time I think your mentor, the founder of Maxtor.

**Warner**: Jim McCoy?

**Carlson:** Jim had decided to leave the company.

**Warner**: Well, he was on the board, but yes Jim was not there at Maxtor on a day-to-day basis. I'm positive, I know this for sure, that if he had been president I would've still been there. So, I don't know what all the reasons were for him not being there.

But before I left Maxtor, Priam (another disk drive company) had declared bankruptcy. I was assigned to go over with a couple other guys and evaluate what they had. They had a five and a quarter full high and a three and a half inch drive that they had completed and for which had the tooling. The drives were operational, and I looked at them and I said, "These are pretty good designs." I said, "For not very much money, we could take them out of the marketplace. Just buy them". And I made that recommendation to the president and he said, "No, no. I don't want to do that."

**Carlson:** Who was the president at that time? Scalise?

**Warner**: Yes

**Carlson:** We did buy MiniScribe. I remember that.

**Warner**: <laughs> Yes, I do. <laughs>

**Carlson:** That got us into the 3 1/2 inch.

**Warner**: Well, you know, we had our own designs but we wound up with MiniScribe. But anyway, to make a long story short, I was also involved with the evaluation of MiniScribe.

  

**Carlson:** And of Priam.

**Warner**: So, when I left Maxtor I actually went over and bought the Priam designs myself. I bought them out of bankruptcy, so I got the designs, all of their lab equipment, their oscilloscopes testers etc. and all the tooling for these two new drives, clean benches, things like that. I paid some cash and some on a note stating that if I we made it successful, they would get this amount for it, and that was the beginning of ORCA.

**Carlson:** Right.

**Warner**: And I had met Dick Reiser before, and Dick Reiser had been their (Priam's) VP of Engineering. Also, the VP of Sales and Marketing. He kind of switched back and forth and sometimes did both at the same time. So, Dick and I got along quite well, and then we met another guy, Won Gil Choe, who was a financial guy who had done business in Korea and Taiwan and Japan and so forth. So, the three of us, formed ORCA, and we rented a building, moved all the stuff in, set up shop, started hiring people, and then the fun began. That was raising money, and creating our business plan. Unlike Maxtor and Micropolis, who did all their (development) work and then manufactured(the drives) themselves, we were going to use manufacturing partners. Micropolis manufactured their drives initially in Chatsworth and then in Singapore. Maxtor did the same thing and set up a Singapore line. Our strategy was to complete the design and testing of the drive but to have a contract manufacturer in someplace like Korea or Taiwan.

**Carlson:** Or Singapore.?

**Warner**: Or Japan. And there were people at that time who were interested in doing that, and it's a model that was executed successfully by Quantum. So we set out trying to find manufacturing partners, and I traveled all over the place. Japan, Taiwan, Korea. I visited all sorts of people. In the end, we got two deals in Taiwan, two companies actually signed up- one to make three and a half, the others to make five and a quarter. They actually made some five and a quarters that they shipped to us, but in the end, both deals collapsed. Why is not completely clear. I also went behind the iron curtain which had fallen. There were some, quote "opportunities" in Eastern Europe We met a guy named Bisser Dimitrov, who came and joined us, and he got some investors from Europe. He (Bisser) came from Bulgaria, and there was a factory in Bulgaria, DZU, that was empty.

**Carlson:** This was the rocket plant?

**Warner**: No, no. It was a disk drive plant, and then there was another in East Germany and another one in Austria. I mean, there was all kinds of stuff going on, so I went to talk with these people and one of the more interesting things was going to DZU in Bulgaria, and here, on one side of the parking lot, was a great big barracks of housing. There was kind of a hall and kind of corporate offices. The other side was a big manufacturing multi-story building, Inside of that building they made 2314s and 3350s. I don't know, but don't think, they had made 3380s yet. They had made a whole pile of IBM drives and they made them *as* exact copies. On one of the baseplates, I think on the 3350, there was a hole for a reason that we (IBM) no longer needed, but we didn't make a change.  They put in that same hole, there was no reason for that hole.

<laughter>

**Warner**: They said they were exact copies, and they made them for the communist bloc.  They provided these disk drives to Russia and to all of the communist nations.  They had a ferrite disk head line where they made their own ferrite, machined it processed it, and attached their in-plant made suspensions.  They had a motor plant, not right there in Stara Zagora, but a few miles away.  They'd had all kinds of clean rooms.  They had an enormous machine shop.  I actually took pictures. I had one of these little paper box throwaway cameras, the kind they hand out at weddings and things like that.  I purchased one of those at the airport before I went in.  Now, this was a very scary experience.  I walked in, quote, "behind the old iron curtain."  The first thing they do is take my passport away.  Then there's a guy there, a driver, to meet me, and he drives me for miles and we visit a floppy disk plant.  We visit a card plant, and then we go further, and we drive out to this lodge.  There is a man and a woman and the driver and myself in this great big lodge.  They fix dinner and I go sleep in a little upstairs room, which had a bathroom, and the bathroom had like a shower, and it sprayed the whole room.  I mean, so <laughs> the shower in the bathroom, the whole thing was, like, a foot and a half or two feet by two feet square.

**Carlson:** Wow.

**Warner**: I mean it was a very, very primitive arrangement.  The next day we go to the plant.  I was toured through and was shown everything.  I was taking pictures of their lines and their machining capabilities and so forth, and it's clear that this factory needed to have something to make.  They were about ready to go under, and our gigabyte capacity eight-disk Priam drive, or the 3 ½ inch Priam drive would've been great for them.

On the trip back to the airport we stopped for something, petrol or something, along the way, and I went into their little store.  The shelves were empty.  I mean, there were a couple of pieces of vegetables and that's it, and guys standing around with nothing to do.  It was evident the country was in dire straits. Later on, I visited the ambassador to England who came from Bulgaria.  I visited his office in London, and we were trying to put some sort of a quote "deal" together.

Also, there was a factory in East Germany that had been making five and a quarter half high drives.  It was based on a design done in San Jose that was transferred to, I think to Taiwan or Hong Kong first, and then it made its way over to Eastern Europe.  So, it was being made there in this factory, and these guys wanted us (Orca) to buy their factory.  They would give us the factory, the buildings, everything.  They had something like 1300 employees, and all we would need to do is move a disk drive production there.  It was fascinating, because they had enormous clean rooms.  They had a whole liquid nitrogen factory in the back.  It cost more to make it in their factory than it did to buy it from West Germany and truck it in.  For example, they had an enormous machine shop.  They were making disk drives, but they had on site at this place, their own fire engines, their own police department, their own hospital, their own cafeteria and security guards.  They had row after row of rooms that were probably 20 by 12, something like that, with a big, heavy door on the front, and you go in a door and there was a post in the middle and a little table and a coffeepot and that room may have rope stored in it. Then you go to the next room and it would have plastic pipe fittings. You go to the next room and it would have metal pipe, and then the next one was locked up because it was full of guns. <laughter>

**Warner**: And so forth. The guys would joke, and say, you know, "This is communism. We pretend to work and they pretend to pay us." They had some very good scientists there working on tribology and things like that. They had an electron microscope that was probably 20 feet high.

**Carlson:** Oh, my.

**Warner**: I mean, it was back from I don't know when, the '30s or something. They had very little modern instrumentation, but they were smart and they did good work. Anyway, we had all these kind of deals going on. Our German and English and Irish investors and Bisser wanted to do things in Europe and not in Asia. I had arranged for loans from, or investments from Hitachi and from other people. All of the sudden, I found out later, the Asian investors got calls, saying "Don't do it, don't do it". Then our European investors forced me out, and within days they put the company into bankruptcy. Then people from Bulgaria came over to start collecting documents and tools and things like that just before the sheriff put the lock on the door. They moved all the equipment out into trucks and took it to Fremont. Later the police found the stuff and they had an auction. I went to the auction to see all my stuff being auctioned off. <laughs>

**Carlson:** What turned the investors sour on these deals?

**Warner**: Well, I don't know that they were sour on the deal. I think that they were trying to put them together. They just figured they didn't need the San Jose operation, and we were not in good financial shape. The production wasn't coming as it was supposed to from Taiwan, and I think the Taiwanese were worried about what was going on within the company, and so in hindsight, it probably would've been much better not to have done any deals in Europe and just continued on with the Asian ones we had.

**Carlson:** If you'd focused on Asia, do you think the investors would've been more inclined?

**Warner**: Well, we would've had Asian investors and not European investors.

**Carlson:** They understand their own territory.

**Warner**: Oh, and I traveled all over the place, talking with people and trying to put deals together here and there. That was a lot of hard work, very frustrating, and in the end it wound up for naught.

So, after I was forced out, then I did a project with Gib Springer to make a very small form factor, one-inch disk drive.

**Carlson:** Yes, I know Gib.

  

**Warner**: And we had a technique for making a very flat disk drive, and we worked on a design for that. The problem was, we couldn't fit the electronics in. We could make the disk enclosure, and the flat motor and so forth, but we couldn't fit the electronics.

I was then offered a job at Toshiba as a VP of Engineer. So I went over there working to help them get the production up and the yields up and so forth. Well, you and I worked together at Toshiba, right?

**Carlson:** That was correct.

**Warner**: And I think Ron Dennison also.

**Carlson:** Interesting experience too. There you got to work for a Japanese owner.

**Warner**: We worked for a Japanese owner and it became pretty clear that Toshiba had a factory in San Jose and was making things so that they could learn everything they could about the technology. Toshiba was very active in laptops. They weren't part of the MITI companies in Japan as far as (access to) the technology. They were left off the list and they needed low-cost, small form factor drives for their laptops. Now, the first drive we were building in San Jose was a 3 1/2 inch and everything was very carefully copied, all of the documents, reports and things like that, were sent back to Japan. It wasn't that long after I joined, less than a year, they decide to close down the San Jose factory, and I stayed on to close it down.

**Carlson:** Yes, I remember that.

**Warner**: I mean, to literally lock the doors. and hold an auction.

**Carlson:** As I recall, part of the story was that Toshiba America is the one who really wanted a 3 1/2 because they had a market for it, but Japan was only interested in their laptop stuff.

**Warner**: Bill, I think that's true, and I think the reason Toshiba, the parent company, went along with the San Jose plan is because they knew that they were going to get something out of it. I mean, they were going to get the testing, the design, the experience, you know, how to. Not that they didn't know how to do stuff themselves, but they got, they tapped into what was the latest stuff that was going on in San Jose. They learned, you know, who are suppliers, what technology to use, what kind of stuff to buy.

So when I finished up with Toshiba, I was going to go work with Gib Springer on making the small form factor disk drives. I then stumbled onto these guys who were making semiconductor packages that were chip scale sized, and that was Tessera.

**Carlson:** Yeah, but before you leave disk drives, Gib Springer had a company called Marqlin, and they were trying to make a, in fact they did make, one-inch disk drive. I don't know whether it was before IBM did it or after.

**Warner**: I don't know for sure either, but I was not part of that.

**Carlson:** You didn't work on that one?

**Warner**: No, I didn't. I didn't work on that, but when I left Toshiba I went to look for the electronics to go with a one-inch drive, and I think that was before Marqlin but I may be wrong.

**Carlson:** So how did you bump into Tessera?

**Warner**: Well, Dr. Kong was a guy that I was introduced to by Won Gil Choe, who was the Orca financial guy, and he (Dr. Kong) had a couple of client companies. I helped him consult on a few things like, for Gusick servo writers and for other people. Dr. Kong had gone to a wedding for the financial lady at Tessera. At that wedding he met Dr.Tom DiStefano and John Smith, and so Dr. Kong said, "Hey," you know, "you're looking for this. You should go talk with them." Well, we did, and John said, "You know, it's really tough time in the disk drive market right now and we're growing and we think we've got the world by the tail with our chip scale packaging," and he said, "We need somebody to make some products for us so we can demonstrate our capability," and I think in his mind we were going to go make products, which I never believed. I joined them and one of the first jobs I had was to go to the computer show and start showing people these chip scale packages. People were starting to now do computers that would fit on your belt and do mobile devices and so they had the same problem that we had. You couldn't fit the electronics in the product.

**Carlson:** You might stop for a second and explain what a chip scale package is for the audience.

**Warner**: Okay. If you looked at an old television set or radio, things like that, you would see these little black packages with these kind of little spider legs sticking out. Well, inside of that package would be a little piece of silicon that does all the work. All these legs and plastic were needed to be able to get the signals out and attach to a printed circuit board. Now, the coefficient of thermal expansion of a piece of silicon is very nonlinear around 3 to 4 parts per million parts per degree centigrade. PC boards are about 18 parts per million per degree centigrade. Whenever you try to put a chip by itself onto a PC board and it would go through a temperature cycle, something had to give, and usually the joints would have to give. So if you tried to make a package the same size as the die, and people had done that, the joints would fail. Actually, IBM had a C4 process where they put pure lead balls underneath the chip and mounted to ceramic, which has a lower coefficient thermal expansion and the lead balls were soft enough that as it heated and cooled the lead would be compliant, and release the stresses. Tessera had figured out a way to fix this problem. At that time they were putting nickel bumps on polyimide tape and then had leads inside the package. So now as the board would expand and with the solder balls attached to the board and the nickel bumps they would follow the circuit board. Inside the package flexible leads were connected to the nickel bumps and then bonded to the pads on the chip. So the chip's moving like this (bending fingers a small amount); the board is moving like that (bending fingers a larger amount), and these leads are busy moving around (flexing) between them (the die pads and the hickle bumps). So, Tessera put an elastomeric layer in between the die and the polyimide that would accommodate those stresses. Tessera produced packages for little chips or die and big die and great big die and so forth.

  

They were working with SUN and Texas Instruments and a few companies like that when I joined. (Tessera called their chip scale packages micro Ball Grid Arrays or uBGAs)

**Carlson:** Intel.

**Warner**: Later on they worked with Intel. The Tessera model was to develop the processes and the technology and then license it and get a royalty. That was their business model. They knew they could participate that way since the packaging manufacturing business by itself is a low margin business. It's done offshore. It's done in Korea and places like that where customers ship them wafers or die and they package them and send them back to the foundry. I think at the time, when I joined Tessera had licensed Shinko as a tape supplier and Shindo and Hitachi for packaging technology and so forth, so they had a few licensees and they had trained people. But when I went to the trade show and talked with people, it was clear that we needed to talk with enough detail that we could provide a solution for somebody. So, if somebody says, "Hey, I can't make my device because I can't fit everything in here," then we would come along and say, "Give us a chance to put it in a chip scale package." So, that's what we did, and that's what I did. I traveled around all over the world, initially mostly by myself. If it was a potential licensee, then usually Tom DiStefano or John Smith would come. Later, when we did military work, John Riley and I would go and teach people about the technology and solve their problems. I would come back with a die layout and give it to Dave Gibson and he would work out the lead routing and design. Then we would make prototypes on our pilot line and provide them to the companies so they could evaluate.

You mentioned Intel. Intel was really the breakthrough for us. Intel met us at a trade show where they were selling bare flash die to people. But to sell a bare die, what they had to do is probe all of the pads for electrical testing. Well, the probes would scar the pads and so the end user had to do wire bonding onto these pads and he would have failures at those scars. So they wanted a package that would be the same size as the die, not any bigger, but it would be testable. We had these bumps so you could test the packaged die and that was going to be their solution for their bare die market. Well, we licensed the technology and they started preparing. They set up a pilot line over by Sacramento.

**Carlson**: Folsom.

**Warner**: Folsom, yes, first a line there and then in the Philippines. But somebody came along and they needed die sized flash memory. Flash memory was used in cell phones, so it was a very high-volume market. A flash memory die is a relatively big die. If you open a phone up it would be one of the larger chip packages.

**Carlson:** A few millimeters? What does big die mean?

**Warner**: They were about three-eighths of an inch or so, and they would go through die shrinks and things like that, so they're not teeny tiny die, but they're not processors die. They were having failure problems because people would drop a phone. Remember in the old days if you'd drop your phone, it was dead.

  

**Carlson:** It's all over.

**Warner**: It's all over. Well, one of the reasons for that is because the die that was in a plastic package on leads had enough inertia when it hit, when the phone would hit the deck, it would create a failure at the solder joints. Well, it turns out with a Tessera type, with this compliant layer, it's like the die is mounted on rubber. Also, you didn't have all the plastic around it so you could make a very thin die package. You could make a tiny solder ball connection so it took much less space, and it turned out to be super reliable. It probably wasn't cheaper, but the phone companies loved them. I think that Intel had 30 percent of the flash memory die in the phone business, before micro BGA, and within two years they had 70 percent. They just beat everybody out.

**Carlson:** <laughs> Good deal for them.

**Warner**: Because it was a much better solution over all. So we did many die package designs for Intel. They put in factories for uBGA packages. They had Amcor and Mitsui High-tec and a few others put in lines. They did an interesting thing in that we (Tessera) had gold leads, and it was hard to source the tape for the package manufacturing. But Intel got Hitachi Cable and Shinko and a few others to manufacture copper leads that were gold plated. So they could do their ultrasonic bond on uBGA gold plated (copper) wire ribbon leads. They would use conventional ultrasonic bonders with Tessera style bonding tools.

**Carlson:** Was the objective simply cost?

**Warner**: It was cost and availability of the tape. They didn't have any reliability problems with it.

You may remember, Bill, that we did a bunch of stuff for the military with this technology, and with testing. They wanted to make sure that these uBGA packaged die were going to work going into smart shells and smart munitions.

**Carlson:** I remember that.

**Warner**: Rockets and smart shells, things like that.

**Carlson:** Mortars and the like.

**Warner**: Smart mortars where the wings would come out and steer them. The military wanted to see whether these would work or not, so we built a thing the size of a mortar shell to fit in a tank barrel and mounted micro BGAs in different patterns. Sideways, crossways, frontways, backways, and then they'd (the military) shoot them from a cannon into straw bales and see if they survived. They all survived. So, you can shoot uBGAs out of cannons. <laughs>

**Carlson:** That's pretty good. Well, you also put it in ears. There was some project on a cochlear implant.

**Warner**: Ah, yes. Cochlear implant was an interesting one. Somebody came to us from Australia that did ear implants in the cochlear. They embedded the chips behind the ear and they have to last for the patient's lifetime as they usually do the procedure on children. It doesn't have to be with children, but oftentimes it is. Then it needs to last the lifetime of the child. So they were interested in the gold lead version of the uBGA for a medical application. Another one was in pacemakers. We had Medtronic come to us and said, "We have this new version. We know by the time it's going to be in production we're going to get this capacity increase in our memory die. We don't have the die now but we need the (storage) capacity now. Can you package two die in the same space?" We came up with a fold-over, if you remember that. We had two die side by side and we'd fold them in the package this way (left palm facing right palm) and the solder balls would be on the bottom. So, you actually, in one footprint, got two die connected in a 3-D fashion.

Then we did 3D packaging with systems in a package. We had designs for a whole radio in a single package. We did lots of really interesting things.

**Carlson:** How hard was it to switch from a career in hard drive technology to something sort of alien, electronic packaging?

**Warner**: <laughs> You know, there's a little learning curve, but I didn't think it was that hard. There's lots of material stuff. There were chemical-properties-

**Carlson:** Which you're already familiar with.

**Warner**: --materials science

**Carlson**: In electronics.

**Warner**: There's a lot of processing. We made the tape designs in San Jose. I had worked with polyimide tapes for cables for magnetic heads (so I had that experience). So I didn't think it was that hard. A lot of the job was selling the industry that this technology was going to be viable, that it was going to last and that they should license it.

**Carlson:** Tessera had a demo line and they made samples.

**Warner**: Well, and remember, you did cost models for us with really elaborate Excel spreadsheets with all different kinds of parameters. Thus we could demonstrate to people that they could actually make uBGA packages in volume and at a reasonable cost. We put a production line in Singapore to demonstrate the same thing. So interesting enough, it's a catch-22. If you don't make a bunch of the packages, then they don't believe you can make it and what the costs are going to be. As soon as you make them they say you're a competitor.

<laughter>

  

**Warner**: So they say, "Why do we want to compete with you guys? You're the inventors. You know all about it," and we say, "No, no, no, no, no. This is as big as we'll ever be. "Go look at the building. You can't make it any bigger."

**Carlson:** But I guess Tessera had changed. They went into optics and decided not to do medical stuff and so on and so on. The culture changed and I guess the management changed and then you left.

**Warner**: I haven't stayed that close with Tessera since I retired. I still see IBMers, because we have lunch twice a year, and maybe 50 or 60 guys come from the old IBM days. I don't see anybody from Micropolis. I have dinner with Jim McCoy at least once a year. Regarding Tessera, I still see Craig Mitchell, one of the guys that works there. My wife Laurie and I are godparents to one of their kids.

**Carlson:** He's still there.

**Warner**: Yes he's still there. I don't go back and make, keep, strong ties.

**Carlson:** Okay. If you had it to do all over again, would you do it differently? Different career or jobs.

**Warner**: No. actually, Bill, I think I was really fortunate to be involved with two technologies that I think made a big difference to the world.

**Carlson:** Me too.

**Warner**: I think doing the hard disk technology work had such an impact on computers, PCs, all the stuff that went on. I was fortunate enough to work for IBM, who had enough money to do all of that, and allow me to make contributions. The next thing, what do we carry around? You know, we carry around phones, cameras and computers.

**Carlson:** It's incredible.

**Warner**: --all that stuff, and chip scale packaging largely made it possible and to made it reliable so that we can carry around and drop it and not break it. That kind of miniature stuff.

**Carlson:** Well, downstairs in the museum they have a replica of the electronics for the moonshot-- Wires all over the place. You probably have more computing power in your cell phone than they had.

**Warner**: Oh, much more. I have much more power in my cell phone than the computer that we did the air bearing programs on.

**Carlson:** It's amazing.

**Warner**: So I feel very fortunate being able to have worked in both of these important technologies.

  

**Carlson:** What's your vision of the future for these technologies? What do you think's going to happen with drives and chip packaging?

**Warner**: Well, we'll see whether semiconductors knock drives out eventually, but the drives keep coming up with higher and higher areal densities.

**Carlson:** Oh, it's incredible.

**Warner:** It's amazing, and we could've talked about some of those technologies, but obviously we don't have time for that, and I have not been intimately involved other than the beginnings of the MR heads, and self-loading sliders and I think about packaging the same way. It'll keep going towards more and more capacity. Probably the limitation just is the heat, and a few things like that. But there are solutions for those problems. We had patents in Tessera to fix those problems. So, I think there's a lot of growth ahead for both hard disk drives and semiconductor packaging.

**Carlson:** I agree. The only question in my mind is reliability. As you get down to where just a few electrons maybe are storing your data, it's <laughter> not the most reliable situation.

**Warner**: I don't know. Well, they'll have redundancy or some other things to make it all happen.

**Carlson:** After your career in technology, you got into the arts and you're building a house so tell us a little about that.

**Warner**: Just quickly. I was worried when I retired, I would not have enough to do. I wanted to do more other things. Actually, I wanted to go sailing. I was planning to do is go sailing around the world.

**Carlson:** Yeah. I remember you bought a boat and a corvette engine

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**Warner**: Well, I owned a sailboat and I actually did sail on a race from San Francisco to Hawaii, in a Pac Cup race. So I've had that experience of crossing the water. My wife has bad knees, so she doesn't like to sail very much. I had another sail boat built but It never was delivered. It's still in Costa Rica. <laughs> A long, sad story, nevertheless. So, we had a partnership later on with our boat. The partners, who have now purchased the boat, are going to take off and sail on the Baja Ha-Ha run to Southern Mexico and then they're going to go across the Pacific.

**Carlson:** That's exciting.

**Warner:** So that was also my plan. So, I was going to do that, but I didn't. Then I've done a lot of home remodeling and rebuilding. We did a place in Willow Glen, and then we downsized to a house in Morgan Hill, and now I'm doing it all over again. So I'm the general contractor.

  

**Carlson:** <laughs> Is that fun?

**Warner**: Yes, I still do wiring and plumbing and things like that.

**Carlson:** I do some of the same stuff.

**Warner**: Yes, I know you do. So I'm still pretty active with home projects.

**Carlson:** You're into cars as well.

**Warner**: Yes. I have a kit car that I'm building, and my wife is on the board of Opera San Jose. She has been on the board for 37 years. She was chairman of the board for seven years or so I love opera, and also jazz. I've been on the board of San Jose Jazz since I retired, which is about 10 or 12 years ago, and I was chairman of the Jazz board for 3 years.

**Carlson:** Well, that's coming up in August.

**Warner**: That's right. So too bad I'm not talking with a live audience here, because in August we have one of the, largest jazz festivals in the country.

**Carlson:** Well, it's every August.

**Warner**: In August we have 12 stages. More than a thousand musicians perform all different kinds of jazz in Downtown San Jose. It's lots of fun. We're also active in the San Jose Art Museum and the Institute of Contemporary Art. I was active in the Computer History Museum until I got my house projects. I hope to get back to that.

**Carlson:** <laughs> And you had cars-- you're building a kit car. You had Jaguars, I remember.

**Warner**: We had Jaguars. I now own a Tesla and a Porsche 944 getting ready for a corvette engine

**Carlson:** Okay. You've gotten into electric cars.

**Warner**: Yes, and I have solar panels. I even have the batteries on the wall, so I'm doing the whole bit.

<laughter>

**Carlson:** Okay. That's fantastic.

**Warner**: And I hope to finish my kit car too.

**Carlson:** Anything else you'd like to add before we close up?

  

**Warner**: No. It's been interesting. I will tell you that-- you've probably noticed I referred to some notes. That's because as I knew this was coming up, I would wake up in the middle of the night for whatever reason.

**Carlson:** Think of stuff.

**Warner**: And I would start thinking of things, and said, "Well, I better write that down."

**Carlson:** Me too.

**Warner**: And then I started -- and so pretty soon I had all these pages. So a couple of days ago I sat down and said, "Let's write them down and put them together." It's particularly fun if you think back and, if you remember back. I can remember back to certain days in the lab what things were there and who the people were and sometimes I can't remember all the names, but I have all kinds of very fond memories.

**Carlson:** Oh, me too.

**Warner**: And I think, Bill, we've been fortunate that we worked around really smart, dedicated, creative people and we are not immersed in a lot of the problems. I mean, we're not surrounded with homeless people in our lives, although I have a homeless guy that I try to keep employed as much as I can. We were not in an industry where stupid people live. So we really got to be around people who were very smart and ambitious and wanted to contribute. I feel fortunate I've had a chance to contribute. I hope to contribute more. I know that you do too. So, my friend, it's been many, many, many years and five companies together...

**Carlson:** 40 years or so. Okay, well, thank you Mike, for your time and interest in oral histories for the Computer History Museum. I'm sure the visitors will learn from your experiences and have a good time doing it.

END OF THE INTERVIEW

ADDENDUM TO THE ORAL HISTORY

After reading over the transcript of my oral history there are two areas about which I would like to make additional comments. The first is about the evolution of the recording technology and the second is about thin film disks and head/disk crashes[1]:

The primary metric for measuring the progress in disk drive technology is how many bits can fit in a given area of recording surface or "bits per square inch". This is the product of the tracks per inch and the linear bits per inch. A number of physical parameters go into determining the linear bit density. These are included in the disk and head designs. To increase bit density on the disk a thinner magnetic layer

[1] This addendum was written by Mike Warner on February 21, 2022.

  

with higher coercivity and fewer defects is needed to be applied to a smoother and flatter disk. The magnetic heads need to fly closer to the disk and have narrower recording gaps and more efficient recording structure with minimum gap losses and improved magnet properties. Higher bit densities resulted in higher data rates for a given disk rotational speeds which required higher speed channels. Higher track densities also required fewer disk defects and also reduced the signal level from the narrow heads which impacted signal to noise ratios. The point of these comments is to highlight that the evolution of higher areal densities requires simultaneous improvements in all aspects of the recording system. All parts of the system needed to evolve together. Improvements in heads, disks, read/write channels, servo systems and their tolerances needed to be coordinated to make improvements in areal densities.

The IBM 3380 machine planned to use 14 inch diameter thin film disks with the thin heads. A great deal of time, years, and money, many millions, were spend on the development of the thin film disk. In the end an improved iron oxide coated disk replaced the thin film disk at the last minute. The problem was head/disk crashes in the machine. It was not an everyday occurrence, but it happened enough that the machine could not pass Product Test. While I cannot say for sure what the mechanism was for the crashes, I do have an observation. In IBM the heads and disks were carefully handled and processed in a very clean environment and the machine had a hepa filter to keep the machine clean. Nevertheless, head/disk crashes were a fairly regular occurrence. These crashes resulted in IBM dropping the thin film disk for the 3380 machine in favor of the more traditional iron oxide coated disk. When I left IBM I worked with thin film disks for use in 5¼, 3½, 2½ and 1 inch diameter disk drives. With 5 ¼-inch drives we used clean rooms in the lab and manufacturing. The drives had a small hepa filter in the air flow that was generated by the rotating disk to keep the drive clean. Head/disk crashes were very rare. With 3 ½-inch drives we used clean benches in the lab and in manufacturing and with a small hepa filter in the air stream in the drive. Again head/disk crashes were very rare. With 2 ½-inch and 1-inch drives the lab work was done in open labs with the spinning drives slipped into and open plastic zip lock bag just to keep spittle off the disk. There were virtually no crashes. Note the tangential velocity near the outside diameter of the 14 inch disk, relative to the flying head, is about 2600 inches per second or about 148 miles per hour. For the 5 ¼- inch drives the tangential velocity is about 930 inches per second or about 52 miles per hour. For the 3 1/2-inch disk drives the tangential velocity is about 600 inches per second or about 34 miles per hour. For the 2.5-inch disk the tangential velocity is about 430 inches per second or about 24 miles per hour. I think with high tangential velocities when the head makes accidental contact with the disk or encounters a particle between the head the disk the impact energy is high enough that damage occurs to the disk surface. This may possible even cause micro melting of the disk surface. The kinetic energy varies with the square of the velocity so the reduction in tangential velocity with smaller diameter disks may explain their tolerance to contamination and reduction in the tendance to create head/disk crashes. Small diameter disk velocities allow the lower energy to be dissipated without damage. This theory could possibly be verified by spinning 3.5-inch disks at nearly 22,000 RPM with low flying heads and see if crashes start to reappear. But who cares now.

  