IBM 1311 (1962-75) and 2311 Disk Drives with 1316 Disk Pack (1964 - late70s)

Typical IBM installation, showing dual 1311 disk drives (Ref 1)

Historical significance

- Media size reduced from 24 to 14 inch diameter, enabling smaller drives.
- Introduced concept of "Disk Packs" as portable memory storage
- Competitive copies of the 2311 launched the "Plug-Compatible" industry
- Allowed unlimited offline storage compared to fixed media drives (1301/1302)
- Facilitated data exchange between separate systems via disk pack exchanges.
- Inaugurated IBM use of FM (double frequency) encoding for improved reliability
- Facilitated segregation and secure off line storage for sensitive data.

Overview

IBM's 1311 introduced 14 inch media diameter as a new industry standard in October 1962, and the final 1311 drive variation was withdrawn in January 1975. The reduced disk diameter enabled a much smaller disk drive than predecessor 1301/1302 fixed media machines which used 24 inch diameter media. The 1311 introduced a removable portable memory, the 1316 "Disk Pack", enabling unlimited offline storage, for which a 1965 patent was issued (Reference 2). A technical description of the new drive design was presented at the 1963 Fall Joint Computer Conference by engineers who helped create it (Reference 3). The entire disk pack weighed 9.4 pounds, less than a single 24 inch diameter disk from the prior generation. The 1311 drive was used on several IBM systems, focused on medium size businesses and scientific computing.

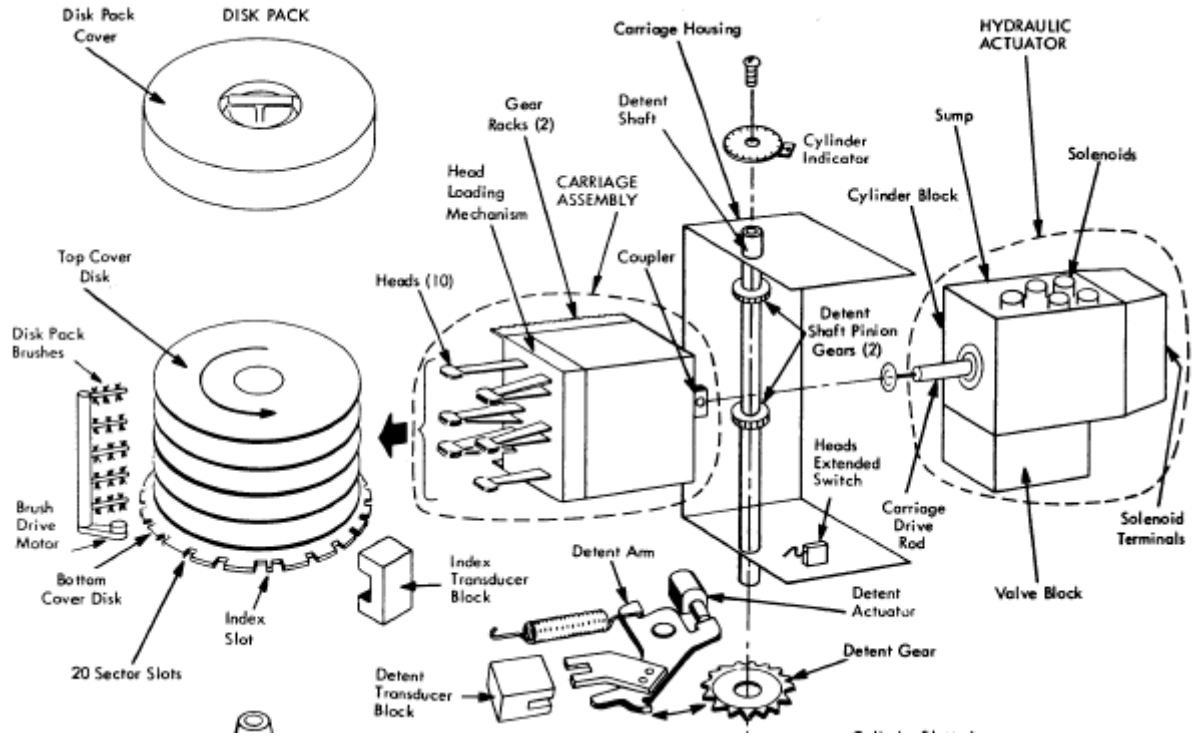
Although the 1311 was first of its kind, the similar but improved 2311 replaced it and was commercially far more successful. The 2311 disk drive was announced in 1964 using the same 1316 disk pack but with updated electronics, and attached to IBM's new System/360 Model 40 computer announced the same year. The 2311 became so popular it spawned an entirely new "PCM" (Plug Compatible Manufacturer) industry, forever changing the disk drive market. The 2311 was withdrawn by IBM in the 1970s, replaced by the 2314 announced in 1965.

Discussion

The 1311 introduced the concept of removable disk drive memory. This interchangeability provided offline disk based storage, limited only by the number of disk packs purchased, and the time required to exchange them … a few minutes per drive. Thus a data center could convert its operation by switching disk packs. This technology also provided the ability to move large amounts of data (pre-internet days), which proved popular with companies needing to update multiple sites (e.g. weekly price updates for store chains). Some new businesses sprang up based on the new business model, one of which was an armored truck company which moved data around with uniformed guards as if data were cash. Some high security installations also used removability to take sensitive data off-line when not in use. A military officer was quoted as saying "I know my data are secure when it's locked in my desk." Military versions of the disk pack were available with metal parts chemically treated to withstand high humidity.

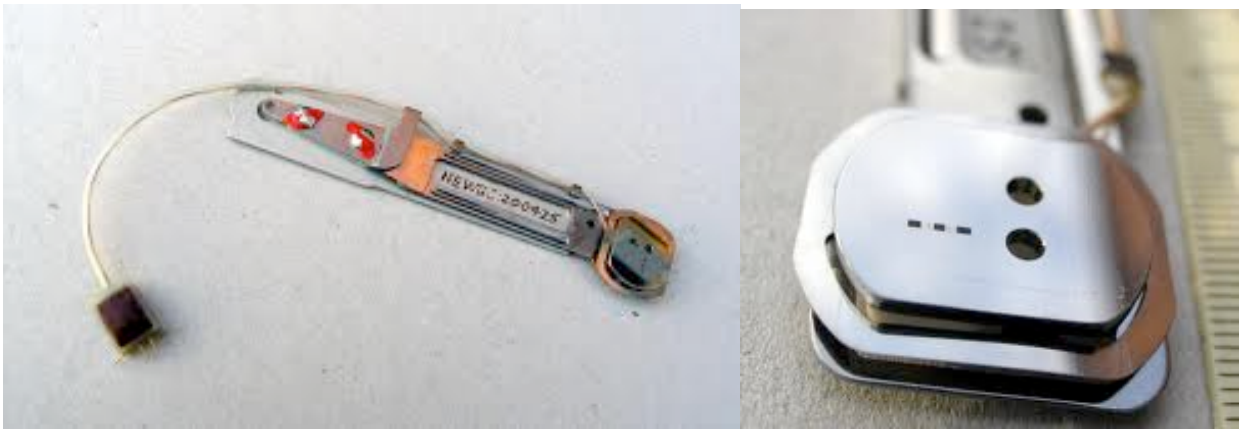
IBM 2311 disk drives open and closed (Ref 4)

The 2311 was outwardly identical to the 1311, with the same size and shape … approximating a top-loading domestic washing machine. Storage capacity (per disk pack) was increased from 2 megabytes for the 1311 to 7.25 megabytes for the 2311. This was accomplished by doubling the number of tracks and increasing linear recording density. Rotational speed was increased from 1500 to 2400 RPM, although customers could reuse their existing inventory of 1316 disk packs. In a typical disk pack exchange, the drive is taken off-line and switched off. After disk rotation stops the drive lid is raised and disk pack removed by attaching a protective cover which has a mechanism to lock the disk assembly into the top cover. A bottom cover then attaches to the disk pack hub as a dust seal. A replacement disk pack can then be inserted and the drive powered up.



Exploded diagram of disk drive and disk pack, IBM Field Engr. 2311 Theory of Operation. (Ref 5)

2311 disk drive transducers (referred to as "heads", "sliders", or "shoes") had stainless steel bodies with "bleed holes" for aerodynamic control and a slot into which the read/write transducer was inserted and mechanically bonded. Heads were mounted on an aluminum arm which was inserted into the disk drive and locked in place. Due to the pack/drive interchange requirement, any drive must be able to read any disk pack, so special "CE-Packs" were employed to align each disk drive head to the center of a reference track. Head flying height (or head to disk spacing) was 125 micro-inches (inner track) to 160 micro-inches (outer track), for both 1311 and 2311.



IBM 2311 Flying Head Assembly (Ref 6)

Part of routine maintenance was to inspect drives for signs of head wear or dark brown stains which would indicate unintended media contact and transfer of the magnetic disk coating. Heads were mechanically pushed into position over a spinning disk using mechanical levers with a downward force of 350 grams. The airfoil lift of the head resisted the downward force of the loading mechanism, the balanced forces providing a stable flying height.

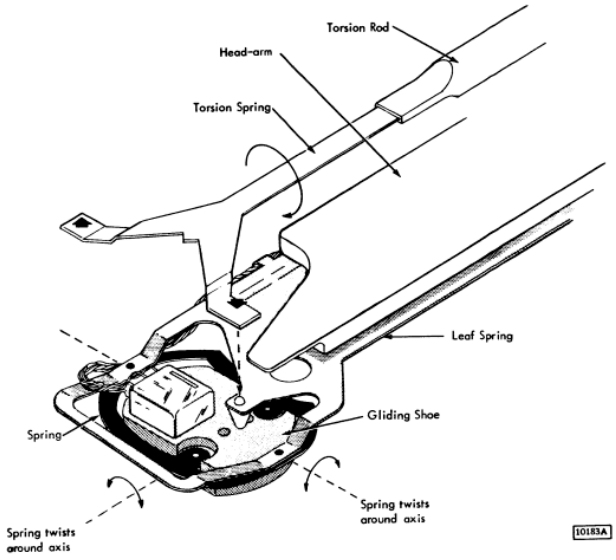


Figure 2-15. Head Assembly and Torsion Rod

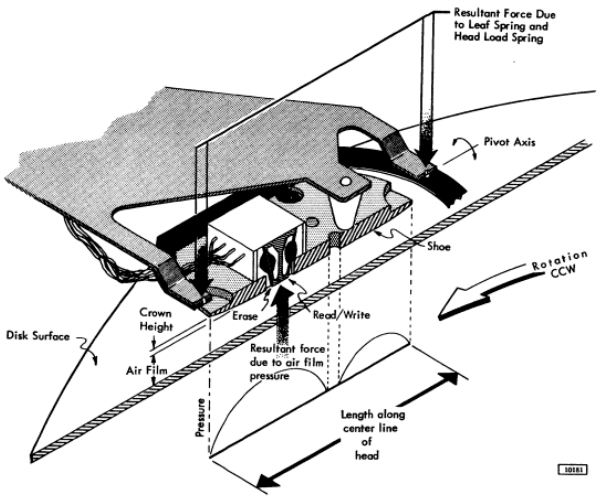


Figure 2-14. "Flying" the Read/Write Head

2311 head suspension Images from IBM Field Engineering, 2311 Theory of Operation (Ref 5)

The 2311 utilized a "tunnel erase" feature whereby data were written with a track width of 0.008 inches, but immediately "trimmed" to a narrower band 0.005 inches wide. The objective was to remove stray field recording which might interfere with an adjacent track, and to provide a tolerance band such that a slight misalignment of the read head due to media interchange would still be able to read the entire trimmed recorded track width.

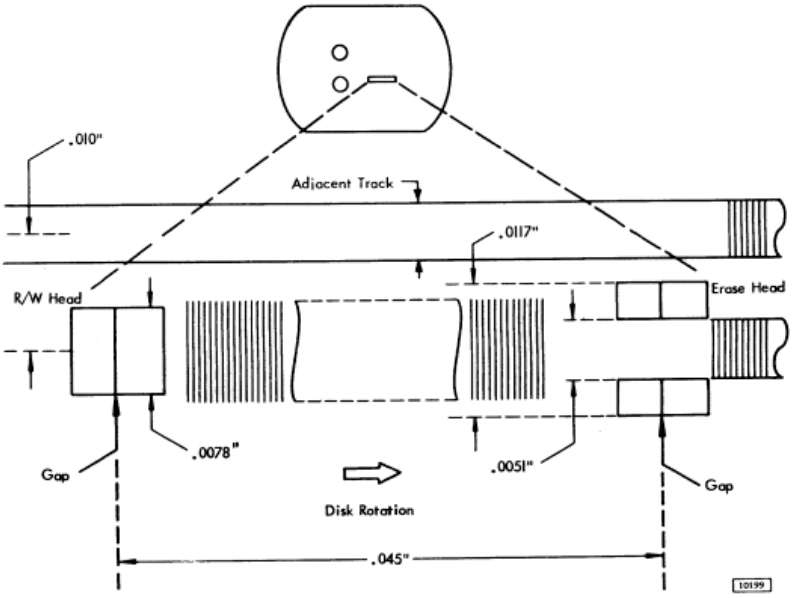
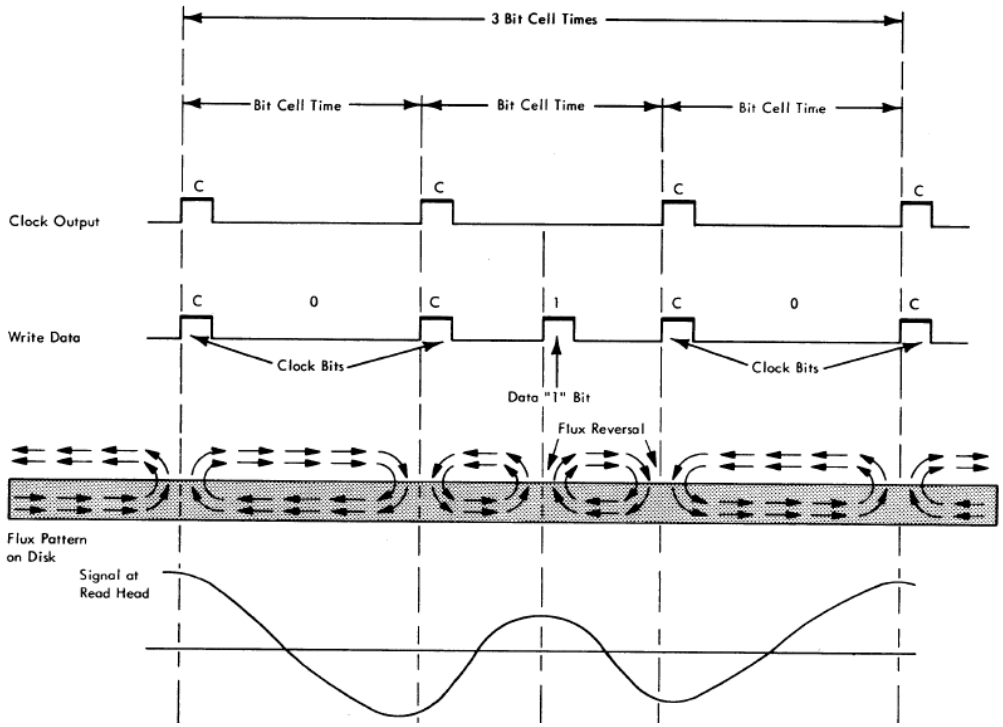


Figure 3-14. Magnetic Head-to-Disk Relationship

Recorded 2311 track width images from IBM Field Engineering, 2311 Theory of Operation (Ref 5)

The recording scheme used by IBM in the 1311 relied on “clocks” which provided timing for data detection, but was changed with 2311 to “Double Frequency NRZ” whereby data timing was part of the recording. In “write” mode, the drive would insert a timing or clock bit every 800 nanoseconds, with or without data. With a “zero” being recorded, nothing would change, so a repetition of pulses every 800 nanoseconds would indicate all zeros. If a “one” is to be recorded, an additional transition is inserted halfway between the clock bits, hence the term “double frequency”. The drive would interpret data 400 nanoseconds after the clock as a “one”. The benefit was self timing, avoiding need for external references as used in the 1311, the downside was half of the recording was for timing purposes, so user data represented one half of the actual recording. This method provided more reliable playback, with data detection governed by the recording itself, and was insensitive to minor RPM variations. (patent references 2).



Magnetic recording pattern image from IBM Field Engineering, 2311 Theory of Operation (Ref 5)

The 1316 Disk Pack consisted of 6 disks in a removable assembly used by both the 1311 and 2311 disk drives. The interchangeable package contains six 14-inch-diameter disks in a four-inch high stack, providing 10 magnetic surfaces for storage (top and bottom surfaces unused). The finished disk pack weighed 9.4 pounds with Polycarbonate plastic covers attached. Each 1311 disk surface contained 20 pie-shaped regions. Sectors were segments of track lying within a region, and were the smallest addressable unit, with a capacity of 100 characters. Average access time to any sector was 250 milliseconds, which could be reduced to 150 milliseconds with an optional direct-seek feature. The disks were rotated at 1500 rpm, tracks (50 to the inch) were recorded at up to 1025 bits per inch, and minimum head-to-surface spacing was 125 microinches. The ten recording surfaces provided in normal usage a storage capacity of 2 million characters (for 1311), the equivalent of approximately 25,000 punched cards or a fifth of a reel of magnetic tape.

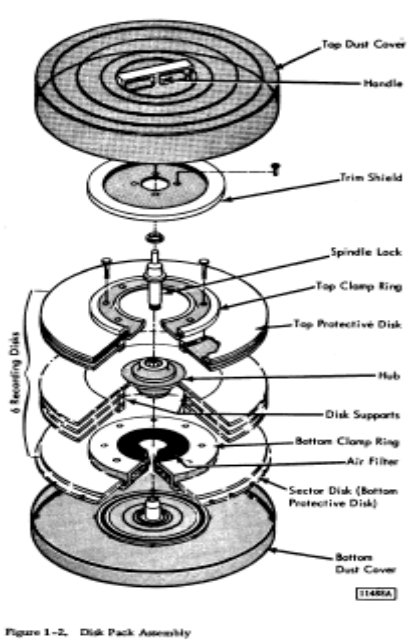
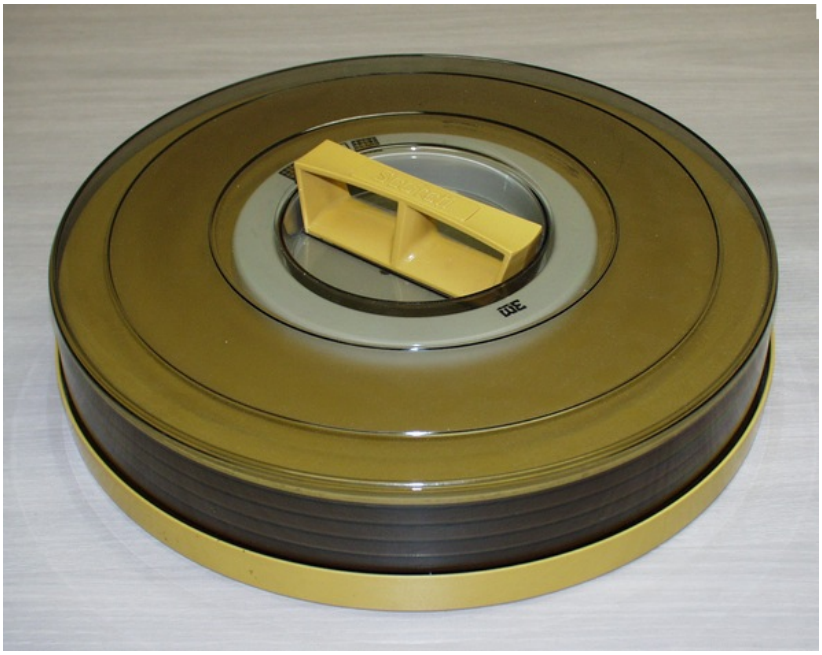


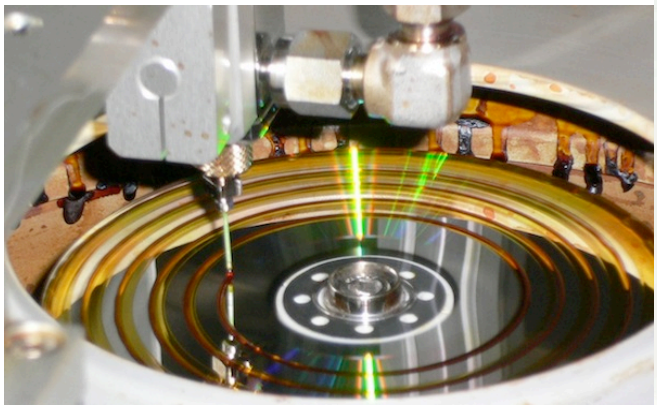
Figure 1-2. Disk Pack Assembly



Disk pack assembly, IBM Manual (Ref 5) **IBM 1316 disk pack photo from "IBM collectables" (Ref 7)**

Disk drive improvements allowed the 2311 to store 7.25 megabytes on the same 1316 disk pack by increasing track and linear recording density. Tracks (concentric cylinders of data) were increased from 100 to 200, and data rate increased from 69 to 256 kilobits/second. Rotational delay was decreased from 40 to 25 milliseconds by increasing RPM from1500 to 2400. The disk pack was intended to be a low cost device, with an established goal of under $100 manufacturing cost. Although this was achieved (Ron Kubec managed the project), accounting policies were later revised with added overhead charges which then exceeded the cost goal.

Disk Media were prepared using a slurry (or "paint") of magnetic pigment in an epoxy-phenolic binder. The application of the slurry was via spin-coating whereby the liquid is poured on a slowly rotating substrate, and the excess spun off at a higher speed. The wet disk binder was then cured in an oven and subsequently polished to a smooth and durable surface. Prior to disk pack assembly the disks were tested in a robotic device utilizing a write/read head on each side. If magnetic testing found a defect, the disk was marked at the edge (actually notched by a solenoid driven chisel) so the defect could be "hidden" in the index gap, avoiding a user observable error. Multiple errors would reject the disk surface, which could be alternatively used as a "end disk" with the error free surface facing a recording head, or on the top "cover disk" of the disk pack where two disks were used for additional rigidity. Disk yield became so high that there were not enough "bad disks" for use as covers, so a special process with low pigment content was developed for making cosmetic cover disks, which avoided the need for polishing and testing.



Spin coating, similar to that used on disks (Ref 8)

Coated disk photo (Ref 9)

Non-IBM competition was fostered by the large success of System-360 and the 2311, which provided standardized attachments starting in 1964. By 1967 the S-360 was responsible for 50% of IBM's US sales, and 70% by 1969. (reference 11). During that time IBM offered a rental plan which provided a 30 day cancellation privilege, intended to facilitate the customer's upgrading to the next generation of IBM hardware. Competitors took advantage of the customer's cancellation ability and ease of connecting their lower priced "plug compatible" disk drives and non-IBM disk packs. Competitive 2311 disk drives were offered in 1969 by Telex, Memorex, and Century Data … and the number of competitors grew. IBM-compatible 1316 disk packs were offered by established firms including Memorex, 3M, CDC, and BASF; plus start-ups such as Caelus, Athana, and CFI (which purchased a San Diego disk pack facility built by RCA). Drive makers also purchased private label disk packs from media vendors, since the manufacture of magnetic disks was not a typical electronics expertise. An early CDC branded disk pack was found to be a relabeled IBM product. In February 1970 an internal IBM report estimated the non-IBM 2311 drive share was only 4%, but expected to grow. IBM responded in May 1971, ending the monthly rental and 30 day cancellation plan by offering discounts for fixed term leases (8% for 1 year, 16% for two years) and no charge for third shift usage ... but increased maintenance charges that July. IBM announced the System-370 series in 1971, which included technical roadblocks for attachment of non-IBM products, but that did not dissuade competitors who continued to add enhanced drives to the large System-360 installed base, some of which outperformed some IBM products on the newer System-370. In the end, plug compatible drive makers often suffered financially by selling below IBM's pricing with products having an on-rental lifetime too short to be profitable. New model disk pack drives (including non-compatible unique versions such as the CDC Storage Module or "SMD") continued being announced into the 1980's DEC RA60 (reference 12) was likely the last significant such product.

1311-2311 Highlights

- Small, lightweight, and removable storage via Disk Packs
- "Unlimited" off-line storage capability at lower cost than multiple fixed disk drives
- Easy transfer of mass storage between systems and/or facilities
- Introduced a more robust recording scheme using self-clocking "double frequency"
- Created a merchant market opportunity for IBM-compatible drives and media.

1311-2311 Lowlights

- Media exchange allowed cross contamination between multiple disk packs and drives
- Required any disk pack to be mechanically aligned to any compatible drive.
- Opening drive cabinet allows contamination entry
- Air filtration inadequate to prevent aerosol and small particle contamination.

References and additional information (underlined items are active hyperlinks)

1. http://www-03.ibm.com/ibm/history/exhibits/storage/storage_1311.html

2. Patent 3,176,261 disk pack design, March 30, 1965 to Robert Pattison, IBM San Jose CA
   Patent 3,356,934 "Double Frequency Recording System", Nov 30 1964, to Martin Halfhill,

3. http://www.computer.org/portal/web/csdl/doi/10.1109/AFIPS.1963.52

4. http://www.computerhistory.org/revolution/mainframe-computers/7/161/569

5. IBM 2311 Field Engineering Theory of Operation, Y26-6897-4, via "Bitsavers.org archives
http://www.bitsavers.org/pdf/ibm/dasd/2311/Y26-5897-4_2311_FE_Theory_Of_Operation_Oct67.pdf

6. http://www.staff.ncl.ac.uk/roger.broughton/museum/DASD/200425.htm

7. http://ibmcollectables.com/gallery/album126/2311_pack?set_fullOnly=on\

8. http://www.hughsnews.ca/verbatim-launches-bd-r-lth-printable-discs-003266

9. http://www.macworld.com/article/1156763/ibm_magnetic_disk.html

10. IBM 2311 Field Engineering Maintenance Manual Y26-5923-5, via "Bitsavers.org" archives
http://www.bitsavers.org/pdf/ibm/dasd/2311/Y26-5923-5_2311_FE_Maint_Man_Feb68.pdf

11. http://www.ebbemunk.dk/misc/ibm360.html

12. http://chmhdd.wetpaint.com/page/DEC+RA60

13. IBM San Jose, A Quarter Century Of Innovation", David W. Kean, 1977, CHM accession number: 102687875

Anecdotes, tales from experiences in the field

1. **Smoke Testing**

   In the early 1960's disk drive contamination testing at IBM was limited to particulates, the standard being "Arizona Road Dust", a commercially available contaminant which was metered into a disk drive air flow to simulate airborne contamination. The time to failure was a measure of resistance to head-disk interference and effectiveness of air filters. Conventional filters consisted of a pleated paper automotive style air filter (reported to be used in a Ford Falcon) on the air input side to the disk pack, plus a nylon mesh filter in the hub of the pack itself to catch any loose airborne objects entering the system between disk pack changes.

   IBM field service engineers called San Jose Engineering to investigate a 2311 installation next to the San Jose airport with peculiar "comet trail" contamination on disk drive heads. The heads were removed and brought to the Building-13 materials

lab. Dr. Irmela Barlow ran infrared analysis on the light brown semi-transparent contamination, revealing a mixture of organic materials, none of which were individually identifiable. She retrieved a technical report from an air quality agency with an absorption spectrum which generally matched the head contamination. The root cause was established as aerosol droplets, probably from jet aircraft exhaust at the airport, with particles small enough to pass through the automotive air filter. At high air velocity in the vicinity of the spinning disk surface, these particles collected on leading and trailing edges of the recording head, appearing as light brown "comet trails".

Once the phenomenon was understood, it was duplicated it in the lab using tobacco smoke from Pall Mall unfiltered cigarettes as an aerosol source, which had an infrared absorption similar to that of the field failure heads. A transparent plastic chamber was constructed with heads and a spinning disk to evaluate exposure to various contamination mixtures. Flying heads were found fairly resistant to problems from either pure aerosols (the tobacco smoke), or by dry dirt (Arizona Road Dust), but a combination of the two caused rapid failure due to formation of a semisolid contaminant. Initially IBM's accounting suspected some laboratory misbehavior after reviewing invoices for several cartons of cigarettes. Lab Technician John Ramos was observed smoking a cigarette in one hand while pumping cigarette smoke into the chamber with the other hand. When asked if he had not learned something about evils of cigarettes doing this work, he replied that he would stick to the brands with filters.

This experience was used to establish the need and to evaluate a new HEPA disk drive air filter, with sufficiently small pore size (approx 0.3 micron) to trap both aerosols and particulates. This is the same filter type used in "clean rooms", and was subsequently made part of next generation drive designs, including the IBM-3330. Milford Kahl of the Product Test Lab scaled up Engineering's "smoke test" to fill a closet sized room with smoke from a gadget smoking about 20 cigarettes at a time, a smelly operation which made the drive under test reek like a cigarette butt, and definitely not shippable after the test.

2. Pot Holder Disk Brake

One customer location in New York was returning 1316 compatible disk packs with the top disks bent down, resembling a slight umbrella shape. Caelus Engineering could not come up with a plausible mechanism which would affect only the two upper disks, so Engineer Manager Bill Carlson was sent to investigate the installation. After interviewing first and second shift operators and observing use of the disk drive and disk packs, nothing unusual was noted … except for a pot holder hanging beside one drive, which no one could explain. Third shift was also reviewed, where one operator was observed to open the lid to the 2311 disk drive shortly after switching it off, then using the pot holder as a hand-held disk brake to reduce spin-down time. Successive applications of downward force had the effect of bending the upper disks. The operator was informed of the problem, and pot holder was put back into the kitchen.

3. Disk Pack Curling

Tom Gardner, one of our senior contributors at the CHM recalled while at Memorex a problem with battered disk packs returned for repair. They were likely 1316 compatibles due to appropriate size and weight. On-site investigation revealed some evening operators were moving disk packs around the floor with brooms, as if they

were pucks in an ice-hockey game. The consequence was predictable due to the "bumper car" events going on between disk packs (and perhaps the walls). The customer was provided with a wheeled cart and advised to not use the floors.

4. **Military Intelligence**
   George Santana, manager of read/write development at IBM San Jose in the 1960s was asking around the lab if anyone knew of an advanced method to recover erased data. The obvious possibilities of looking off-track for residual signals could be handled by off-track overwriting of data, but he was looking for something more sophisticated. When asked who the customer was, the answer was "Military", apparently some secret data needed complete assurance of destruction. After several weeks the subject came up again in a hallway conversation, and when asked what the customer did … George responded "they burned the disk pack". With a funny smile he added … "they burned the recording heads as well".

Primary Author: Bill Carlson