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July 30, 2009

This paper is to record some of my experiences as an independent provider of cleaning, adjustment, and other services in the maintenance of traditional analytical balances in the 1940's and 1950's.

I learned my vocation as a teenager working with my father, Nicholas H. Krayer, who had a large clientele primarily in western Pennsylvania, western New York, throughout Ohio, and West Virginia. While many balances requiring service were found in laboratories quite advanced for their time, such as the research laboratories at United States Steel, Gulf Research, the Aluminum Company of America, Mellon Institute, Battelle Memorial Institute, various university and government laboratories, and the research laboratory at Proctor and Gamble in Cincinnati, most of our work was in industrial laboratories performing routine but essential quality control analyses of their products or for the processes in the steel mills, glass factories, chloralkali and other chemical companies, paper mills, tire companies, coal companies, makers of creosote and other chemical byproducts of the steel industry, and companies making special additives for the steel industry. Industrial companies of almost all kinds were in full production during the World War II years of the early 1940's, but the steel mills in particular were in constant need of our services. Their work was demanding and the laboratories – for example, located on the open hearth floor – were susceptible to gross vibration, often containing an obvious layer of grit throughout the laboratory, and frequently having a pervasive atmosphere of acid from the laboratory procedures. In the late 40's also, as I continued to work on my own (beginning in 1948 after my father's death), I recall the bare hillsides around the zinc works (for galvanizing) associated with the American Steel and Wire plant in Donora, where nothing could grow, in the Monongahela valley, which soon had the notorious three-day smog that killed several people. Diesel engines had yet to dominate the railroad industry, and many of the laboratories were located near railroads emitting huge amounts of dark smoke from coal-burning locomotives, also creating their own vibration. Air conditioning was unheard of in the industrial laboratories, and simple fans sometimes blew ash and other solids into them from outside.

In virtually all situations, the first thing we did was to clean the balance. This was hardly ever simply a matter of wiping the knife edges and bearings as indicated on pages 27 and 28 of my grandfather's book, "The Use and Care of a Balance." Routinely, the front sash would be removed completely so the glass could be cleaned on the inside as well as outside. All the other glass had almost always to be cleaned inside and out also. To do this, and to inspect the knife edges and bearings, the beam had to be removed and in many cases the pan arrests also in order to do a decent job on the base. Brass parts – operating rods, the central post and the like – could become corroded or tarnished. Even chromium plated parts, and the rhodium plated parts introduced by Ainsworth, would corrode or tarnish under harsh lab conditions. We used fine carborundum or emery paper and steel wool on them, and coated them with lacquer. The wood cases sometimes acquired spectacular grubby smudges at points near where fingers constantly manipulated the knobs and buttons. These would be removed (I always carried Spic n' Span). It should be remembered that, while many users were thoroughly educated chemists and respected their balances, others, particularly those performing repetitive analyses in industrial quality control laboratories, were paid by the hour, trained only for specific routines, and occasionally, but often enough, had a disrespectful attitude about any company property. This was especially true of shift workers in spite of frequent admonitions from the laboratory management. Bent parts, broken glass and the like were not uncommon also in student balances, which were a dependable source of work for us.

Virtually all makes of balances had lead counterweights for the front sash, and sometimes these would become inoperable because the cord connecting the sash to the weight would wear out and/or break. We carried new sash cord and screw eyes in case somehow the attachments were broken. I replaced many sash cords in all kinds of balances. Pan arrests were also a source of simple mechanical problems. They were typically operated by a push button or knob on the front of the case, connected to a rod passing through a coil spring and having some sort of catch device**;** the pan arrest frame was mounted on a pivot which was sometimes fouled by corrosion or dirt. We carried new springs and other parts for various makes of pan arrests.

Ainsworth balances were popular in the industrial laboratories, and elsewhere in the above described territory, because they were rugged while still dependably delivering accurate results. The type TC, having a keyboard and a series of internal weights, was often used for the critical carbon analyses in the steel mills for this reason. The aluminum cases of these and virtually the whole line of Ainsworth balances, however, could in the worst circumstances become corroded, generating the white powdery oxide alongside a peeling coating.

If the subject was a chain balance, more often than not the chain would be removed and cleaned with a solvent during the general cleaning process – that is, before testing it, and in fact, the whole mechanism, whether dial or post, including the vernier, would often be dissembled and cleaned. Chains in laboratories working with fats and oils were particularly likely to have films of material settling on the chains from the atmosphere. A dirty chain not only meant errors, but erratic errors depending on whether the first and second readings were at opposite ends of the 100 milligram range or close together within the range. Similarly, balances which had a beam roller, usually one which weighed one gram and was moved from notch to notch, almost always required that the roller be cleaned before testing, since it was liable to have been dropped a few times as well as having accumulated its own dirt deposits. We did not attempt to clean the smaller wire riders. For testing chains and roller weights, we carried well-protected, and frequently checked, standard weights.

Sometimes parts were replaced rather than attempting to fix or correct them. We carried new chains, whole new Chainomatic setups, pointers (my grandfather calls them indexes), roller weights, whole sets of interior weights for keyboard balances, rider pickups, felt pads for the pan arrests, and pans. Some pan surfaces originally had thin coatings of lacquer, which could wear off or become stained**;** we might use steel wool on their surfaces without applying new lacquer because of the possibility of weight changes under varying atmospheric conditions.

Magnetic dampers were very effective in speeding up the weighing procedure, but sometimes an erratic performance by a balance could be traced either to a poorly positioned vane or magnet, or a magnet having trapped a magnetic particle. Here, our own polishing efforts with steel wool were sometimes indictable – steel wool was the magnetic damper's worst enemy.

Perhaps the two most often mentioned weaknesses of the traditional balance were (1) the tendency of one side of the beam to become effectively longer that the other and (2) the tendency of the knife edges to drift or move, becoming out of parallel. Almost always, the two maladies were related. Appropriate adjustments are well addressed in my grandfather's book beginning on page 18, but the examples used are on balances having plenty of set screws so the relative positions of the knife edges can be adjusted, such as in Sartorius balances. While I worked on more than a few of these, by far the vast majority of my work was on balances having the knife edges swaged into trapezoidal slots in the beam. The knife edges were made with a slight taper to facilitate this. Both the knife edges and bearings on which they acted were made of hard Brazilian agate.

On pages 10 and 11, my grandfather describes testing for arm length. In practice, both my father and I **always** assumed that our two large weights were not equal, and therefore we transpositioned them during the test, as alluded to on page 11. In fact, we **knew** they were not equal because we carried them around continuously in our work bags. The two particular weights we used, moreover, were 100-gram weights fitted with hooks made of brass wire about 4 centimeters long, soldered to the tops of the handles of the weights. The hooks were seriatim placed on the front and back of each stirrup while the other weight was on the opposite pan, to obtain estimates of any arm length differences between the front and back of an end knife edge. The test was repeated after exchanging the weights. The results enabled us to correct an errant knife edge parallax at the same time as arm length error in general. I usually finished the diagnosis with a simple drawing of three parallel, or not so parallel, lines and a dot as an indication of where best to make the adjustment.

When there are no set screws to turn, and the knife edges are swaged directly into the metal beam, other steps have to be taken to adjust arm length and misalignment of the knife edges.[1] My father perfected a technique of tapping the metal next to the knife edge, slightly deforming the beam to cause the knife edge to move. He made a special tool by grinding away a portion of the shank of a screwdriver, and removing the screwdriver handle, creating a device having a narrow working end and the ability to detour around the top of the metal beam so the working end of the tool could be placed flat on the metal of the beam. We had a small hammer and a small anvil on which the beam was placed before tapping the beam at the desired point. Frequently the operation would correct the knife edge parallax as well as the arm length with a single stroke. We were aware of a possible hysteresis effect after such a minor deformation, but had no way to measure it. In fact, it was not unusual to find, on a two-year regular schedule,

[1] Cf. George McPhail Smith, "Quantitative Chemical Analysis" p. 19: "Anyhow, if the weights are always placed, say, on the right pan, such a correction is unnecessary in ordinary analytical work, because the weights observed are proportional to the true weights, and the ratios obtained are not affected."

that another such operation had to be performed. Of course, an analogous phenomenon occurred with the set screws in Sartorius and other balances.

On pages 12 and 13 of my grandfather's book, he discusses how to determine that the knife edges are worn or dull, among other related matters. In addition, my father and I used the "fingernail test," usually to confirm the more sophisticated diagnosis. My grandfather does not mention another related, and common, defect – a groove worn in one or more bearings – which was observed in many cases to coexist with a dull knife edge. Such a groove could be readily seen with the naked eye, and was a clear indication that, in addition, the knife edge was dull. Sometimes this was evidence of poor stewardship, in that the users did not bother to lift the beam off the bearings when the balance was not in use, but other times it simply reflected the atmosphere of the laboratory. A dull knife edge is bad enough, but resting in a groove presents additional poor response and erratic readings. Classical cures include replacing the offending parts or repairing them. Repairing them means removing the knife edges from the beam, and the bearings from their settings (hardly ever the ones in the stirrups – the whole stirrup would be replaced), and applying them to an oilstone carried with us, with the aid of jeweler's rouge. This was a skill I practiced reluctantly, and was always a major undertaking because the sharpening and polishing were time-consuming, and even though meticulously carried out, the results were sometimes dubious; moreover the parts then had to be correctly replaced. After sharpening the knife edge(s) and polishing out the groove, replacement meant not only a complete readjustment of the knife edge alignment, but making sure the replaced center bearing was as level as I could make it. Although this option was used occasionally, there were far more instances in which I applied a more gratifying solution, contriving to shift the arm arrests so placement of the entire beam was moved a millimeter or more, assuring a new resting place for the center knife edge on the undisturbed center bearing. Failing that, and especially if the balance had other problems, I would simply recommend to the owner that the balance be junked, making sure he saw the groove. For those instances in which the decision was to replace a part, we carried a number of new and used knife edges and bearings of various sizes; the used ones had been sharpened or polished in our home shop, where my father had built a motorized lap furnished with a rotating polishing stone. I much preferred to do my sharpening and polishing work on this device where the rotation speed could be controlled, and only a steady position and pressure were required rather than a back-and-forth motion which inherently risked a rounded surface.

Another skill I learned from my father was how to drill holes in glass. This was done in the home workshop also, the most frequent subject being the large glass base having as many as eight holes for various purposes. The places for the holes would be marked on paper glued to the glass blank (sold as "black carrara" and ¼ to 3/8 inch thick), then the appropriate diameter bit would be placed in a drill press. For smaller holes the bit would be a simple brass rod, and the drilling agent would be loose carborundum grit lubricated simply with water; grinding through would take perhaps twelve minutes with gentle pressure. For larger diameter holes, such as for the central post, a tube was used, resulting in a glass disc inside the tube. We made many glass bases as well as side windows having holes for the rider controls.

During my apprenticeship with my father and afterwards, I sometimes carried balances to our car and repaired them at home.

Because my father had to limit his travel during his long recuperation from a heart attack, he also designed a lamp for balances, and we made them in the basement shop. Sometimes we would see a rather warm or even hot incandescent lamp lying on top of a balance, defying my grandfather's advice on page 29. My father used a fluorescent light and suspended it in front, rather than on top of the balance. We made a number of these and sold them until, I believe, the laboratory supply houses began to imitate them. My father had excellent relations with the local laboratory supply house named Burrell, and especially good relations with Fisher Scientific, which served a large territory and was headquarted in Pittsburgh. My father also was very well respected by the Ainsworth management, which offered me a position in the company as a tribute to him after his death.

Among the parts we carried were new pointers or, as my grandfather called them, indexes. Replacing one for whatever reason would always call for a reestablishment of the desired sensitivity (sensibility in my grandfather's book). This is simply loosening the set screw on the weight that it holds, and moving it up or down to move the center of gravity of the beam. Adjustment of the center of gravity in this manner did not strictly address the problems illustrated in Figures 1 and 2 of the book, where the knife edges are not in the same plane. Where the center knife edge was found to be in a plane higher than the two end ones, it was, as my grandfather says, more often than not due to a dull center knife edge. While sharpening is indicated as appropriate therapy, this will result in an even more heightened center knife edge**;** accordingly replacement of the knife edge was sometimes performed. This was done only reluctantly, however, since there was no precise or scientific way to pick the right replacement, which in any event had to be followed by readjustment of the knife edge alignment. This problem can be remedied relatively easily on the Sartorius and other German balances by adjusting various screws, as described by my grandfather. If the problem was due to a distortion of the beam – a bending downward on both ends probably due to placing excess weights on it – or in some other cases, we could in some instances provide a whole new beam, but this was not common.

I did not attempt to calibrate weights, and when the customer inquired, I referred him to the manufacturer, which almost always offered a calibration service.

Many of the problems of the traditional balance were obviated by the constant weight, single pan design introduced by Mettler primarily in the 1950's, and the role of the itinerant balance service man was much less important thereafter.

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