Lubrication in Historical Meteorological Instruments: Tribology, Metrology, and Restoration Practice

Leo Shirokov

July 24, 2026

1. Introduction: Lubrication as a Metrological Problem

Let me begin with a personal observation, because it explains why this subject deserves a discussion of its own. Over years of working with aneroids I have opened dozens of instruments, and by far the most frequent cause of their failure was neither capsule fatigue, nor deformed levers, nor wear — but an excess of lubricant applied with the best of intentions. The classic example is a drop of oil on the pointer arbor, a trick that circulates through collectors' advice as a universal way to 'revive' an instrument. In reality that drop begins to collect dust, and a decade or two later what one finds in its place is not lubricant but a hard conglomerate of oxidized oil and mineral dust. It does not merely increase friction: in several instruments that have passed through my hands it had fixed the pointer arbor solidly in its bracket, turning a moving joint into a permanent one. The instrument looks immaculate; the pointer stands perfectly still and does not move at all.

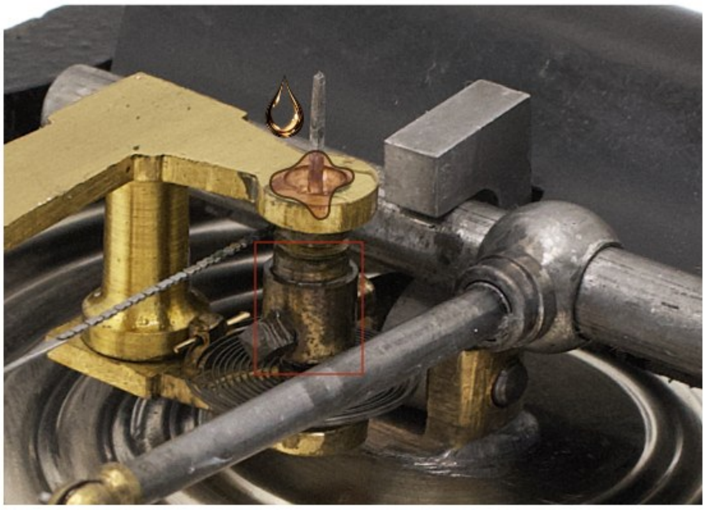

Fig. 1. Pointer arbor of an aneroid barometer glistening with oil; the marked area shows where a conglomerate has formed, blocking the arbor's rotation.

I have observed the same mechanism of damage on the bell crank of the main arbor, which turns in a pivot bearing. Flooded with oil, it first lags, then moves in jumps, and finally stops turning altogether — and the transmission of motion from the capsule to the pointer arbor ceases. Tellingly, in all these cases the aneroid capsule itself was alive and sound: what ruined the instrument was not the physics of elasticity but the tribology of intervention.

Hence the general statement of the problem. Mechanical lubrication is the introduction, between contacting surfaces, of a substance or thin film that reduces resistance to relative motion, wear, and the likelihood of seizure. In a coarse machine, lubrication above all protects the parts from destruction and overheating. In a precision instrument of the nineteenth and twentieth centuries it acquires a different meaning: it becomes part of the measuring system. Resistance at the pointer arbor, the viscosity of oil in a micro-clearance, a chain sticking to its drum, or a contaminated hairspring change not the instrument's longevity but the very result of the observation [17, 18, 19].

In a power mechanism — a clock driven by a mainspring or by weights, for example — there is a reserve of energy sufficient to overcome friction in several dozen bearings. Clocks tolerate regular oiling precisely because the energy of the mainspring or weights is comparatively large, and the task of the mechanism is the steady transmission of motion. In a measuring instrument the source of motion is weak: in an aneroid barometer it is the elastic deformation of an evacuated metal capsule under changing atmospheric pressure. The deformation is small, the travel of the levers amounts to fractions of a millimetre, and the torque at the pointer arbor can be so small that a drop of over-viscous oil acts no longer as a lubricant but as a damper: the instrument becomes a low-pass filter and stops responding to rapid pressure changes [9, 1, 6].

This is why the basic terms of tribology carry a metrological meaning here. Friction — resistance to relative motion — produces reading error. Stiction — static adhesion, usually exceeding dynamic friction — produces jerky pointer motion. Hysteresis — the mismatch of readings when the same value is approached from different directions — arises in a barometer not only from the elasticity of the capsule but also from friction in levers, chains, and arbors. Viscosity determines the resistance to shear in a thin film. Capillary action holds oil in the cup of a jewel, but just as readily carries it away onto a hairspring or a dial. Wear changes the geometry of pivots and holes. A lubricating film is useful while it is stable and thin, and harmful once it turns into a sticky bridge. Boundary lubrication, in which the surfaces are separated by molecular layers rather than by a full hydrodynamic wedge, is the most typical regime for slow-moving instrument mechanisms [17, 18, 16].

Modern guides to meteorological observation stress that what matters for aneroids is not only absolute error but also temperature compensation, long-term stability, and low hysteresis. For aneroid barometers, WMO-No. 8 specifies requirements for accuracy and for a small difference in readings after a pressure cycle; this effectively frames friction as a problem of measurement quality, not merely of repair [1]. For historical instruments the task is harder still: old oils oxidize, dust becomes an abrasive, and the restorer must choose between preserving the historical state and recovering working motion [12, 14, 13].

2. A History of Lubricating Precision Mechanisms

The early lubricants of precision mechanics were almost always of organic origin. Clocks, navigational instruments, and laboratory mechanisms used animal fats, vegetable oils, spermaceti and sperm whale oil, bone oil, refined neatsfoot oil from the hooves and shins of cattle, and mixtures with waxes or graphite. Their virtue was availability and the ability to form a thin film on steel and brass. Their vice was chemical instability: unsaturated components oxidized, the oils thickened, turned acidic or gummy, absorbed dust, and became paste [2, 3, 8].

In nineteenth-century horology the oil problem was discussed with exceptional practical concreteness. Watchmakers knew that bad oil does not stop a watch at once: first it increases the scatter of the rate, then it darkens, gathers dirt, and wears out holes and pivots. The manuals repeat the requirements to clean pivot holes with pegwood, to remove old oil, and to apply a small quantity of fresh. Saunier, in The Watchmakers' Hand Book, insisted that holes and pivots be thoroughly cleaned and that oil be applied sparingly, so that it stays at the end of the pivot rather than spreading over the plate; similar practical rules appear in Britten and, later, in the manuals of de Carle and Gazeley [2, 3, 4, 5]. The remark bears directly on aneroids: there, excess oil is more dangerous than moderate dryness.

In the eighteenth and nineteenth centuries there was also a debate about dry versus oiled bearings. In coarse clocks and tower movements, dry running quickly caused wear. In high-grade pocket watches lubrication was obligatory in the train pivots, but certain nodes of small amplitude or particular geometry were treated differently. For scientific instruments the question became finer still: if a part hardly rotates and only performs micro-oscillations, oil does not distribute evenly. It is either squeezed out of the contact zone or, on the contrary, accumulates in one spot and creates sticky resistance [7, 6, 16, 17].

In the second half of the nineteenth century mineral oils gradually displaced many of the organic ones. They resisted oxidation better, had more predictable viscosity, and were less prone to turning rancid. Yet early mineral oils, too, were inconsistent: fractional composition, sulphur impurities, the degree of refining, and additives strongly affected their ageing. The twentieth century brought purpose-made clock and watch oils, and then synthetics based on esters, silicones, and hydrocarbons with narrowly specified viscosity. For micromechanics this was a revolution, but it did not remove the main question: does this particular bearing need lubrication at all, and will it change the instrument's sensitivity more than it reduces wear [3, 4, 6, 12]?

Fig. 2. A modern Moebius watch oil.

Oil ages by several mechanisms. Oxidation produces acids and gums; evaporation of the light fractions raises viscosity; polymerization turns the film into varnish; dust and corrosion products make the residue abrasive. In a historical aneroid this shows itself as a sluggish movement: the pointer lags behind the pressure change, then jumps. In a barograph the pen draws a smoothed curve in which part of the meteorological information has been lost to the instrument's internal friction [12, 13, 1].

3. Horology as the Technological Source of the Aneroid

The aneroid barometer did not arise in a vacuum but within the culture of nineteenth-century precision instrument making. Lucien Vidie built the first workable metallic barometer in 1843 and patented it in 1844; the British patent No. 10157 was obtained in October 1844 through the agency of P. de Fontainemoreau, and the patent rights were held until 1855 [25, 9]. But turning the idea into a production instrument depended on an infrastructure that already existed: watchmakers, dial engravers, spring makers, steel polishers, masters of gearing, makers of fine chains and of jewelled bearings. The aneroid therefore inherits the language of horology: pivot, jewel, hairspring, lever, sector, rack-and-pinion, fusee chain [25, 9, 10, 11].

In a clock, the pivot bearing transmits the rotation of a wheel at a relatively regular speed. Conical and rounded pivots were polished to a mirror finish to reduce the contact area and to hold the oil at the end of the pivot. Jewelled bearings of ruby, sapphire, or garnet reduced wear and preserved the geometry of the hole for decades. The fusee chain served to equalize the torque of the mainspring: winding onto the cone of the fusee, it compensated for the fall of spring force as the spring ran down. The balance hairspring supplied the restoring torque; the gear train carried the energy from the barrel to the escapement [7, 2, 3, 6].

Fig. 3. A clock fusee chain.

In the aneroid these elements change function. The fusee chain transmits micro-displacement from the lever system to the pointer arbor; the hairspring removes backlash and maintains tension; in aneroids with a rack-and-pinion movement this unit amplifies the travel and turns the pointer staff; elastic bimetallic elements correct the influence of temperature. Jewelled ruby bearings likewise remain in use in precision barometers and altimeters. But the energy source in an aneroid is not a mainspring: it is atmospheric pressure acting through a thin elastic capsule from which the air has been pumped out. This changes the friction budget in principle. A clock can afford to spend part of its energy on overcoming the viscosity of oil; an aneroid cannot. In a clock, a bearing that is too dry accelerates wear and degrades amplitude. In an aneroid, surplus or over-thick lubricant simply masks a small change of pressure [9, 1, 20, 22].

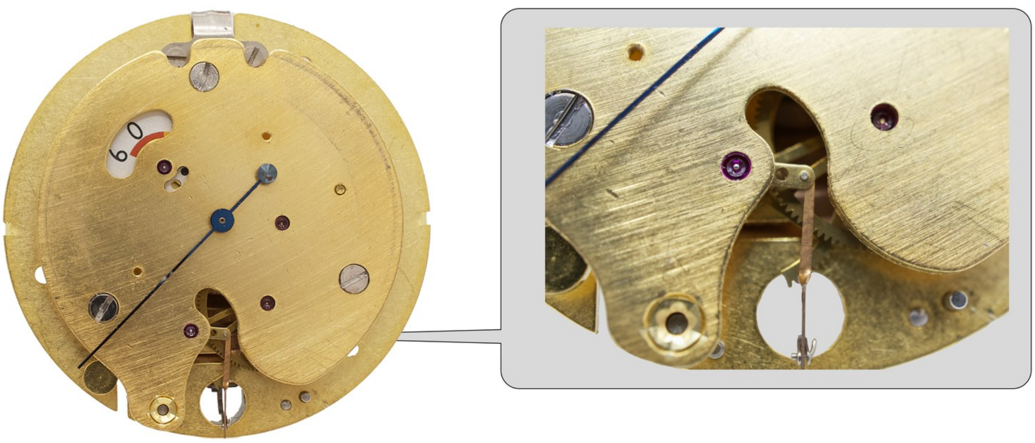

Fig. 4. A Thommen altimeter with jewelled bearings.

Makers such as Negretti & Zambra, Naudet, Short & Mason, Richard Frères, Casella, Fuess, Goldschmid, Paulin, and others worked within different national traditions. The English school stressed practical reliability and marine and expedition service; the French — elegance of mechanism, compactness, and serial finish; the German — laboratory accuracy, standards, and engineering system; the Nordic school, represented by the system of Paulin, a Swedish engineer and inventor, — null-method instruments for altimetry. These distinctions should not be absolutized, but they help explain why outwardly similar movements could have different lever schemes, different modes of temperature compensation, and different philosophies of maintenance [20, 21, 22, 23, 24, 26].

4. Lubricating Aneroid Barometers and Barographs

A typical aneroid consists of one or several evacuated capsules — thin corrugated metal boxes from which the air has been removed. Atmospheric pressure tends to squeeze the capsule; the elasticity of its material, or an auxiliary spring, resists; and the small displacement is transmitted through a system of levers to the pointer. In a barograph this system is joined to a recording arm, a pen, and a clockwork drum that rotates the chart [9, 1, 20, 21].

From the standpoint of lubrication the mechanism divides into three classes of nodes. The first is the elastic sensing elements: aneroid capsules, hairsprings, compensating elements, links. These must not be contaminated with oil at all. An oil film on a hairspring changes its effective stiffness, makes the coils stick together, and creates a temperature-dependent error. A link joint is a pin in a free hole or a hook in an eye; oil there fills the clearance, the menisci pull the pin toward both walls at once, the viscous film begins to transmit parasitic forces — and since the amplitude in such a joint is fractions of a degree per day, the lubricant is never renewed there: it ages in place and, with dust, petrifies. The second class is the micro-moving joints: knife-edge bearings, point and pivot bearings, suspended links. Here, too, near-dry operation with a perfect polish is preferable. The third class is the more heavily loaded, genuinely rotating elements: the clockwork drive of the drum in self-recording instruments (barographs, thermographs, hygrographs), the drum arbor with its gear, the drives of electromechanical precision aneroids. These nodes are close to clockwork, or are clockwork, and require ordinary but moderate lubrication [2, 4, 6, 20, 22].

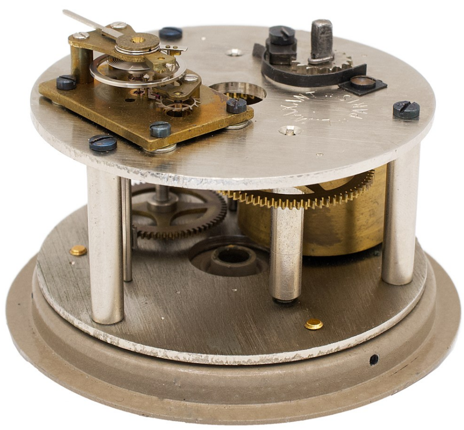

Fig. 5. The clock movement of a Maxant barograph.

Excess oil degrades an aneroid in several independent ways. First, viscous resistance to shear at small amplitude is comparable to the measuring force itself. Second, surface tension holds parts together: a fine chain lying in the groove of a drum no longer re-lays itself freely but drags like a wet thread. Third, capillary forces carry the oil along a chain, a lever, or an arbor, contaminating the dial, the hairspring, or the chart. Fourth, oil holds dust, and dust in an instrument with a small driving force is no longer mere dirt but a mechanical stop;

this is exactly how the conglomerates described in the introduction arise, jamming the pointer staff or the bell crank solid [17, 18, 16, 12].

Hysteresis in an aneroid is of mixed origin. Part of it belongs to the metal of the capsule: elastic deformation is not always fully reversible, especially after ageing, temperature cycling, or overload. But a large share of the practical hysteresis arises in the transmission: a pivot must break away from rest, a chain link must change its contact, a rack tooth must cross to the other side of its clearance. Old oil increases precisely this component. As pressure rises the pointer moves differently than as it falls, even when the capsule itself is perfectly sound [1, 9, 17].

For this reason historical instruments were often designed to minimize the need for lubrication. A knife-edge support carries the load on a line of contact and, given good material, runs practically dry. A suspended link replaces a rotating joint with a flexible suspension. A fine chain works better clean and dry, merely protected from corrosion, than bound with oil. Only a bearing with substantial travel and genuine rotation may need a microscopic drop of light oil [10, 20, 21, 23].

5. Fusee Chains: Corrosion, Sticking, Cleaning

The fusee chain of a clock and the fusee-type chain of an aneroid look alike but differ mechanically. In a clock the chain transmits considerable torque from the spring barrel to the fusee; it works permanently under load, passes through appreciable angles, and link wear is a real problem. Tellingly, even here the horological tradition prescribes fitting the chain dry: oil in the joints creates no useful lubrication regime, but it does hold abrasive dust inside the clearances and glues the links together [7, 2, 3, 6].

Fig. 6. Fusee chain of an aneroid barometer.

In an aneroid the chain serves not to transmit power but to transmit micro-displacement without backlash. As a rule it runs from the upright arm of the main-arbor bell crank to the pointer staff, converting linear travel into rotation of the pointer. The load is small; the motion is slow and usually less than a full turn. Here oil forms no hydrodynamic regime at all; it creates meniscus forces between neighbouring links. If the links stick together, the instrument loses its sensitivity to small changes of pressure: the pointer begins to respond only once enough force has accumulated — that is, it shows not a continuous process but a series of delayed jumps [9, 20, 17, 18].

Grooved fusee drums, and the small chain drums that embrace the pointer staff, add a problem of their own: oil is held in the groove by capillarity. With changes of temperature it migrates, thickens, or runs out onto the plate. In a clock, active motion at least redistributes the lubricant; in a barometer it stays in one place for years and ages locally. Chain wear in an aneroid is usually a lesser danger than corrosion and sticking. Historically, therefore, the sensible philosophy for such chains was cleanliness, protection from humidity, and minimal or zero lubrication — not regular oiling [12, 2, 3, 22].

And yet the collector's hand reaches stubbornly for the oiler — and it is most often the chain that suffers. It is assembled from dozens of flat steel links joined by riveted pins; the clearances in its joints are measured in hundredths of a millimetre. For the pointer to answer a pressure change of a fraction of a hectopascal, every link must articulate freely, and the chain as a whole must obediently wrap a staff of small diameter, kept taut by a spiral hairspring. But atmospheric moisture, condensation cycles on a cold wall, and hygroscopic dust set off electrochemical corrosion on the steel. Its products — hydrated iron oxides and oxyhydroxides — occupy several times the volume of the parent metal. Forming inside a joint clearance, rust acts as a wedge: link after link seizes, and the supple chain becomes a rigid strip. It stops wrapping the staff and introduces elastic resistance and friction into the transmission; the pointer acquires hysteresis and sticks, answering only the habitual tap on the glass — and the stiffer the chain, the larger the jump after the tap. In advanced cases corrosion eats through the pins and the chain breaks: its strength is that of its worst pin.

The reflex 'if it creaks, oil it' is here not merely useless but harmful, and for several independent reasons. First, oil does not restore mobility: the oxide wedge in the joint is chemically inert to hydrocarbons and stays where it is; the apparent freeing of the chain after a soaking is an illusion that lives for weeks. Second, oil ages: mineral oils oxidize and polymerize into a varnish-like film, while the old organic ones (bone oil, neatsfoot) release, in addition, free fatty acids that themselves promote corrosion. Mixed with rust and dust, the result is an abrasive adhesive paste — the links end up glued twice over, by oxide and by varnish. Third, oil migrates: capillary forces carry it along the chain onto the pivots of the pointer staff and onto the hairspring, whose coils stick together — and new faults are added to the old. Finally, a thin oil film is no barrier to water vapour and does not stop corrosion already under way beneath it [17, 18, 12].

The sensible strategy is not to preserve the rust but to remove it without touching the metal. The chain, once taken off, is first degreased in benzine or isopropanol: old oil will keep an aqueous solution from wetting the joints. Then comes chelating cleaning: near-neutral solutions based on complexing agents (the classic conservation option is ammonium citrate at about 5%; ready-made chelating rust converters with no acid base also serve) bind the iron oxides selectively without attacking sound metal. Exposure takes hours; an ultrasonic bath helps the solution penetrate the clearances. Strong mineral acids are better avoided: apart from etching the riveted pins, acid pickling of hardened steel risks hydrogen embrittlement — and for a part working in bending and tension that is a death sentence. After cleaning, the joints are worked free mechanically, drawing the chain under light tension over a polished mandrel of small diameter until every link turns freely. The finish is a rinse in distilled water, displacement of the moisture with isopropanol, and quick drying in warmth: freshly cleaned steel is prone to instant flash rust. The criterion of success is simple and visible: hung freely, the chain must fall in a smooth catenary, without kinks or memory of shape [12, 13].

Protecting the cleaned chain is a task not for lubrication but for a dry barrier. Museum-grade microcrystalline wax, applied from a white-spirit solution in a micron-thick layer with the surplus wiped away, leaves a dry, non-tacky film that gathers no dust, does not creep, and does not age into varnish. The rest is a matter of climate: relative humidity below roughly 50%; no condensation cycles — do not hang the instrument on a cold outside wall, and do not bring it straight from frost into a warm room; in storage, silica gel in the case, or paper with volatile corrosion inhibitors. And one point that is often forgotten: the chain should be handled only with tweezers or in gloves — a fingerprint, with its chlorides, etches polished steel more surely than many a reagent [12, 13, 15].

The transmission that carries motion to the pointer staff — fusee chain or toothed rack — was conceived dry in the aneroid, and dryness here is at once a sign of health and a recipe for longevity. Lubrication, in this context, is not conservation but deferred failure.

6. Point Bearings, Pivots, and Microfriction

Point and conical pivots, and knife-edge supports, were the instrument makers' answer to a single task: to reduce the friction torque under a small driving force. In an ordinary cylindrical pivot the contact depends on the load, the quality of the hole, and the presence of oil. In a conical or point bearing the contact area is small, but the demands on polish and hardness rise sharply. Mirror polishing reduces the micro-interlocking of asperities. The pairing of hardened steel against agate or ruby gives a stable combination of materials. Agate and ruby bearings in scientific instruments were valued not as ornament but as a way of keeping the contact geometry for decades [2, 3, 6, 10].

Fig. 7. Main arbor of an aneroid movement, disassembled: bell crank with ball collar and clamping screw, slotted upright arm for the fusee chain attachment, flat spring link, and a pair of cone-point pivot screws (screw centres) with mirror-polished tips.

Micro-contact mechanics shows that real surfaces touch not over their whole apparent area but at individual asperities. Under small loads each asperity acts as a separate barrier. Oil in the boundary-lubrication regime reduces adhesion and wear, but at very small travel it is never renewed. If the oil ages, the boundary layer becomes a sticky film. The question 'to oil or not to oil' therefore has no general answer. The fast-turning pivot of a barograph's clock drive must be oiled. The point bearing of an aneroid's bell crank works best clean and dry — and it is this bearing that the superfluous drop most often kills. A steel arbor in a brass hole with appreciable rotation wants a drop of light oil; a steel-on-steel micro-joint of small amplitude is more sensitive to viscosity than to wear [17, 18, 19, 16].

Fig. 8. Cone-point pivot screw (screw centre) of the main arbor: the mirror-polished tip forms the bearing point on which the arbor turns; the opposing pair sets the arbor's end play.

The old masters solved all this empirically: polish, hardening, the choice of stone, the geometry of the cone, minimal play, protection from dust. The modern restorer can describe the same things in the language of friction coefficient, surface energy, and capillary retention, but the practical conclusion remains the old horological one: cleanliness matters more than oil, and oil belongs where it stays put and where it genuinely reduces the losses [2, 4, 5, 13].

7. Barographs and Recording Mechanisms

The barograph complicates the aneroid with two systems: a battery of capsules connected in series, and a recording drive. Several capsules are joined to increase the total travel; a lever amplifies the displacement and guides the pen across the chart; a clock movement rotates the paper drum. Two maintenance regimes therefore coexist within a single instrument. The sensing transmission must be nearly inertia-free and low in friction. The clock drum and its train are serviced as a clock [1, 20, 21, 22].

Fig. 9. Pen types of self-recording instruments.

The pen and ink system adds a source of friction of its own. The pressure of the pen on the paper must be minimal: enough to record, not enough to brake the lever. Ink dries out, adds resistance, fouls the pivot of the pen holder. In the old barographs of Richard Frères, Short & Mason, Negretti & Zambra, or Casella the quality of the trace depended not only on the capsules but on how freely the pen glides over the paper. The wrong paper, over-thick ink, or excessive pen pressure create an error indistinguishable in appearance from friction in the transmission [21, 22, 20, 1].

Manufacturers usually distinguished the servicing of the clockwork from the servicing of the sensitive movement. The drum's clock drive was oiled periodically with a light clock oil, while the levers, links, and hairsprings demanded cleanliness and caution. In museum practice a barograph may be preserved as an object not intended for continuous recording; the lubrication of its clockwork is then minimized or replaced by conservation protection. In a working restoration, by contrast, the drum's regular running must be secured — without extending that rule to the whole instrument [4, 5, 12, 13].

8. Restoring Historical Weather Instruments

Modern conservation science distinguishes conservation from restoration. Conservation seeks to stabilize the object, to preserve its material and the traces of its manufacture and use, and to make every intervention documented and, as far as possible, reversible. Restoration seeks to return function and appearance, sometimes at the cost of replacing parts or removing later traces. For a historical barometer the distinction is fundamental. If the instrument is a museum piece, its accuracy as a measuring device may be secondary; if it is to work in a collection or in a demonstration, mechanical function becomes part of its value [14, 13, 12, 10].

Cleaning old oils calls for caution. Organic residues sit next to varnishes, shellac, painted dials, paper charts, adhesives, and patina. An aggressive solvent will remove not only the oil but the historical finish as well. The restorer therefore first documents the condition, identifies the materials, tests solubility on a small area, and only then cleans. In sensitive nodes it is better to lift the contamination mechanically and locally than to flood the instrument with solvent [13, 12, 14, 15].

The philosophy of minimal lubrication matters especially for aneroids. It does not mean 'never lubricate anything'; it means that lubrication must be local, compatible, stable, and functionally necessary. Modern synthetic oils are useful because they age more slowly and have a specified viscosity. But their surface tension and creep differ from those of the historical oils; some silicone fluids migrate with extraordinary ease and contaminate surfaces that will later resist painting or gluing. A wrong choice of modern oil can create a problem the historical instrument never had [12, 13, 18].

The danger of over-oiling is not merely aesthetic. Surplus oil reaches the hairspring, binds its coils, alters the temperature compensation, holds dust, produces pointer lag, stains the dial or the chart — and, at the limit, as shown above, immobilizes a moving joint entirely. Collector practice is rife with the mistake 'the instrument is old, therefore it must be oiled.' For clocks this is already an oversimplification; for aneroids it is, more often than not, vandalism. Diagnosis must come first: are the levers free, is there corrosion, is the capsule deformed, has the zero screw been disturbed, does the pointer rub against the glass, is the pen pressed too hard? Only then is the question of oiling specific bearings decided [4, 5, 20, 12].

It is worth stating separately that the museum approach gives priority to authenticity and documentation; a working restoration allows more active intervention — disassembly, cleaning, spring replacement, dial adjustment, the choice of oil; and collector practice occupies the middle ground and depends on the owner's skill. A scientifically honest approach requires one to record that recovered sensitivity is not the same as historical accuracy: after cleaning and modern lubrication an instrument may work better than in the late period of its service life, yet it no longer reflects the state of its historical use [14, 13, 10].

9. A Special Case: Combined Instruments

The lubrication story has an aggravated variant — combined instruments, in which a clock movement and a barometric movement share a single case. In my collection this variant is represented by a Soviet Mayak wall clock with barometer and thermometer — represented, alas, vividly.

Fig. 10. The Mayak clock with a barometer in a shared case.

These clocks have a design peculiarity which, in a conversation about lubrication, turns from a curiosity into a risk factor: the mainspring of the clock movement sits not in a brass barrel, as in most clocks, but in the open. A barrel, after all, is not only a power unit but a container: it keeps the spring's lubricant with the spring. An open mainspring is the largest lubricated surface in the mechanism, hung out directly into the shared volume of the case.

What this means in practice I saw on opening the instrument after its purchase. Inside, a thick oily mush awaited me, smeared over literally every part of both mechanisms — from the clock's wheel train to the levers of the aneroid unit. The diagnosis needed no expertise: someone in the past had oiled the spring with a generous hand, and the spring then did the distributing by itself. At every winding and every run-down the coils of the ribbon slide over one another, squeezing the surplus toward the edges, from which the oil creeps and drops onto whatever lies nearby. And nearby — directly below the clock movement, since the instrument hangs vertically on a wall — sits the aneroid unit: gravity faithfully delivered to it everything that ran down from above. Mixed with dust, the oil turned into the very abrasive adhesive paste discussed earlier, and the instrument's operation was disrupted completely.

Here lies the problem of combined instruments as a class. A clock movement is a machine that tolerates lubrication and, in measured doses, requires it: pivots, pallets, mainspring. An aneroid is a device that lubrication kills. So long as they live in separate cases, each is serviced by the rules of its own craft; even in a barograph, where both systems stand on one plate, the clock drive is structurally set apart in its own block. But in a combined instrument the case is one, the air is shared, there are no partitions, and everything fluid, volatile, and sticky instantly becomes common property. Hence a simple rule: the maintenance regime of such an instrument is dictated by its most delicate tenant. Lubricate only what the design provides for, in watchmaker's doses, from the tip of an oiler; the spring — with the thinnest layer of a dedicated grease, not 'until it shines'; and not a single drop in the hope that oil will 'fix' anything.

Another example of a combined instrument is the Richard pocket altigraph, in which, likewise, the clock movement and the barometric movement sit in one compact case in close proximity to each other.

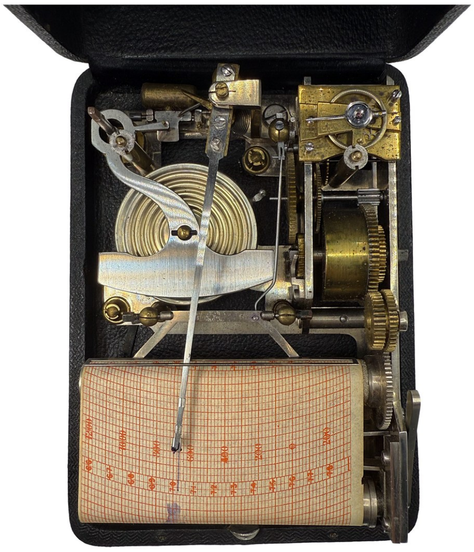

Fig. 11. The movement of a Richard pocket altigraph.

The restorer of a combined instrument has to be two specialists at once — a watchmaker and a barometer conservator — and, in every node, to choose the stricter of the two professional cultures.

10. Conclusion

Lubricating historical meteorological instruments is not a narrow repair question but part of a fine balance between sensitivity, stability, longevity, and accuracy of measurement. In a clock, oil helps the mechanism spend a comparatively large reserve of energy without destructive wear. In an aneroid barometer or a barograph the same gesture turns a sensitive instrument into a viscous system with lag — and, at worst, into a motionless sculpture of its own mechanism. The aneroid thus occupies an intermediate position between the clock and the scientific measuring apparatus: it is built by the means of horology, but it must be judged by the criteria of metrology [9, 1, 2, 6].

Historically, instrument makers solved this task with polish, hard materials, small contact areas, jewelled bearings, chains, hairsprings, and minimal clearances. Oil was one tool among many, not a universal remedy. Modern restoration should continue that logic: first understand the function of the node and the scale of the forces at work, then clean, and only then lubricate — where it is necessary and reversible. In an aneroid, good lubrication most often means nearly invisible lubrication; and, not seldom, its deliberate absence [10, 17, 12, 13].

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