Fountain Pen Design

Function, Development, Construction, and Fabrication

Amadeus W. Füller, Ingeneer
fountainpendesign.wordpress.com

Contributions by Tal Schriftsetzer

Contents

1 Introduction

1.1 Welcome to Fountain Pen Design

... a collection of stories about my adventures developing a fountain pen in the late seventies

It was in the middle of the year 1978 when a fountain pen model landed on my desk in my laboratory. Actually, they were two models of the same pen, each made from a solid piece of painted Perspex and wires. One showed the pen as it would look with the cap on and the other one without a cap, an *appearance model* we call it in the trade.

It took almost three years for the "penwright" (me, the ingeneer[1]) to not only fill the pen's interior to make it write but also, to circumnavigate the design (shape) hurdles the designer (shaper) had placed on its path, hindering completion; of course not intentionally but by naïf ignorance. At your leisure, I recommend your lecture of the book about the *Lorelei*[2] sitting on a rock in the middle of the fast-flowing River Rhine. She had been totally oblivious that her appearance and singing distracted the skippers, and they collided with the many rocks. Just like that.

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Let's begin the journey. What is so special about Fountain Pens? As you keep on reading along, you will discover, it's a miracle that they work at all. Building something on such aloof grounds was a big hurdle to jump for an ingeneer who likes rising from a solid foundation. Did it work out? Have a

[1]There is a reason for this spelling of ingeneer. See page 314.

[2]https://en.wikipedia.org/wiki/Lorelei_(name)

read, and you will find out. (It sure did; who wants to write about something which didn't?)

Now, about this book: No stress! You won't find long tables of test results but information you will find helpful for understanding fountain pens' function. Each topic unravels in a similar way. After introducing you to some general information, I continue with providing enough scientific background so that you can follow my explanations on the technical and quality details of form and function, as well as the production of the components pertaining to this topic. Finally, a chapter will be rounded off, with a bit of discussion.

A good starting step for a novice would be from Components of a Fountain Pen.

How does magic enter into the design of a pen? I love my work, am passionate about it and I highly care about the user of my product. And for now, it is my wish that you get much pleasure from reading and discovering.

1.2 How my website was initiated

I love telling stories.

Friends and Fountain Pens

On Saturday, the 9th of May in the year 2008 anno Domini, I had temporarily left this world allowing myself to delve into the metaphysical spheres of my mind. This is definitely my most favourite pursuit.

Dreams, the past, the future and many of the innumerous present moments invited me to feel joy. Reminiscing about the good old days evoked memories of fountain pens, which to me means the stories about their making. And as so often, I got infected by my own excitement and one story shook hands with the next. During a moment of mental rest, I thought absent-mindedly: "You should write all these things down."

I call this angel talk, which happens every now and any odd year. Each time, it spurs me to leave things behind and devote my attention to new horizons.

Alas, referring to me writing about fountain pens, most often, life lured me to other fields of enjoyment. On several occasions, I wished to return to writing about pens; however, I experienced an annoying writer's block, and absolutely nothing wanted to appear on paper (on the computer screen). Just in time, I received a letter with, most astonishingly, my address, handwritten. What a rare thing in this time of the information age.

When I opened it, I found that the entire letter had been handwritten in ink, written by a long-standing friend.

He explained that he intended to write with his fountain pen again, for many reasons. Last, but not least, for the exercise it provides to the brain. He elaborated: "One has to construct a sentence before writing it and holding it while writing. In comparison with using a word processor, the required brain capacity is far greater."

Figure 1.1: Sheaffer Targa 1001XG

Nostalgia touched me, and I cleaned my favourite fountain pen, a Sheaffer Targa 1001XG. After several years of resting in a jar with other 'low level' pens, after refilling, the old faithful returned to service, no problemo. Even better, the excitement triggered by this job inspired me to write again. Where would we be without our friends?

What rekindled the topic was me pondering on the origin of the word fountain pen, no new thought for a pen designer, undoubtedly. The comparison with a fountain, a well spurting out an endless amount of water sounded too far-fetched. To shed some light on the matter, I wondered what people in other countries call a fountain pen.

1.2.1 Origin of a Word

Countries with their language based on Latin (French, Italy, Spain), call the fountain pen *stylographe*, *estilografica* and *penna stilografica*. You recognise the two Latin root words *stilus* meaning pointed instrument and *graphicum* standing for writing implement, which adds up meaning: pointed writing implement.[3]

[3] *Penna* is the Latin word for a contour feather – a feather with a central shaft to which vanes are attached. This links all modern pens to one of their historical origins: attached to birds. In a similar link, Islamic calligraphy is performed with a *Qalam*, a word that traces back to the Greek word for a reed: *kálamos*. (https://www.iranicaonline.org/articles/qalam-pen)

I also would like to turn your attention to the Wikipedia[7] information on fountain pen's history and technology, which even includes events, which occurred in the 'Rest of the World' ... outside the US of America.

I would like to finish this introduction by quoting a sentence I found on the Internet:

> "Today, a majority of modern fountain pen users use fountain pens as their primary writing instruments over ballpoint and roller ball pens for reasons related to writing comfort, expressive penmanship, aesthetics, history and heritage."

With all this in mind: Enjoy reading and discovering

1.3 Components of Fountain Pens

It's always good to start with definitions; it assures us that we find ourselves on firm and common grounds. Having built my fountain pen in Germany where it is called *Füllfederhalter*, a long, good, reliable word, meaning a fillable nib holder. In German, the most significant component of a collated word is always the one at the end, namely the holder. In other words, I want to say that English terms for several components were unfamiliar to me, but either way, I still did not always agree with the definitions and translations but here we go. These are several definitions I discovered:

A fountain pen is:

- A pen with a reservoir filled with ink that automatically feeds the writing point.
- A pen that is supplied with ink from a reservoir in its barrel.
- A mechanism that is composed of three main parts. The nib, which is in contact with the paper. The feed or black part under the nib controls the ink flow from the reservoir to the nib. The barrel holds the nib and the feed on the writing end protects the ink reservoir internally. The part close to the nib is the part that you grip while writing.

[7] https://en.wikipedia.org/wiki/Fountain_pen

- A pen that contains an internal reservoir for ink.

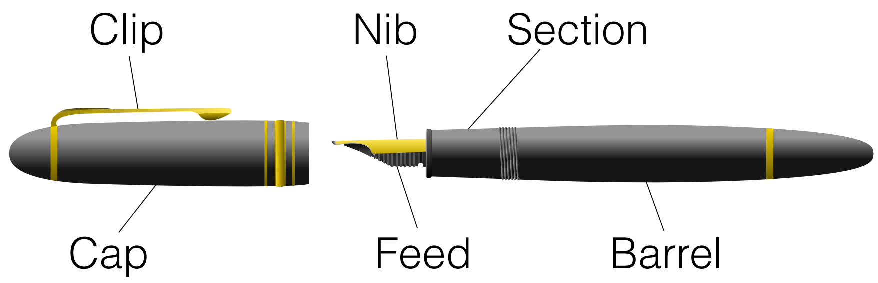

Figure 1.2: The visible components of a Fountain Pen. Invisible, are the Care of the Ingeneer, the Quality of the Maker, and the Joy while writing

Believing strongly that you expect more than these brief statements, rest assured, I will write about the fountain pen and its components more in-depth. The focus will be on the function of the components, the underlying mechanics, physics and a subtle smell of chemistry, the manufacture and their testing. The explanations will remain as general as possible so that you can apply your gained knowledge to explain the specific execution of a component you may find in your fountain pen.

1.3.1 Feed

In my early days of trying to work out the feed's purpose, I drew up a flowchart of its functions, interactions, and feedback loops.

This I considered being very sensible because, after my graduation in 1970, I had worked in the field of designing computers. At uni, computers had been dinosaurs, taking up a whole floor, but now I was faced with forefront technology aimed to build the first mobile computer based on semiconductor integrated circuit technology. Then, I built a basic calculator as a hobby (1970!) applying this technology.

From this time on, my way of thinking adhered to this genre. Hence, inevitably, I concluded, that the complex task of this small piece of plastic could only be fulfilled through the control of a microprocessor. Innocently I suggested my idea to management (I had not learned to know them), they looked at me as if I had teleported from Mars to Earth, this very moment.

With a bit of help from miracles, I managed to develop a feed without a microprocessor. Last but not least, I had to because at that time, 1978, they had been still too large to fit inside a pen.

Seriously, today (2014), with microchips being so tiny and being cheap as chips, as well as with nanotechnology around, I wonder why no one has taken on the task to integrate a processor into a feed.

1.3.2 Nib

It is probably the most significant part of a fountain pen. It is here, where it all happens. The ink is transferred to the paper. The style of nib determines the characteristics of writing when the width of line alters in response to the writing pressure the writer applies, providing the writer with an opportunity to form an expression, only surpassed by the brush.

1.3.3 Ink

Although, along with paper and pen, it is one of the significant constituents of writing, designers and ingeneers usually neglect it.

I invested some time studying rheology, fluid statics and dynamics. After building rigs for standard test methods, I developed several reliable test methods, particularly for the realm of ink and pens. This allowed me to brew my own ink to specifications much narrower than standard inks. After this, my early studies on surface actions between ink and plastic became reliable and the test results predictable.

Through this dependable ink, the research and design of my feed were based on reproducible tests, it achieved a reliable function, permitting my fountain pen to time-tested quality performance. Otherwise, it would have been long forgotten. Time weeds without attachment.

1.3.4 Section Assembly

The main components of a fountain pen are contained in the section assembly, namely: The grip itself, the feed and the nib. Once these components are assembled the testing of a fountain pen's function can begin.

2.5 Application to the Feed

Return to the Bubble Bottle

How do surface tension and capillary forces work in the feed? In Figure 2.1 from the chapter Bubbles and Bottles, the problem was to get air inside the bottle/reservoir. Water outlet and air inlet are determined by the same component, the bottleneck.

I always found it to be good ingeneering practice to have a component or an element of it carry out one function, only. This permits to adjust this function without affecting any other, or at least minimise the interference. I show this in Figure 2.17.

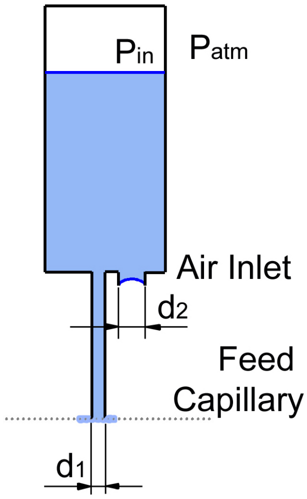

Figure 2.17: Separating functions: feeding ink, air inlet

The first function is "feeding the ink". For this, I chose a narrow capillary, d_1 (two, actually, about that, later). The second function controls the entering of air (air inlet). The surface tension will prevent the ink from flowing out through the air inlet because the diameter d_2 is smaller than the maximum diameter the surface tension can bridge. The diameter needs to be smaller because it not only has to hold the ink column resting above it but also resist the possible increase of air pressure inside the reservoir. Note: d_1 is much smaller than d_2.

Like in Figure 2.2 in the chapter about Bubbles and Bottles, in our current example the ink is drawn out of the reservoir by the suction of the paper (could be any other method), hence, the vacuum P_{in} increases. When the resulting forces between the vacuum and the atmospheric pressure P_{atm} are stronger than the surface tension of the membrane at d_2, the membrane ruptures and lets in a bubble of air. You know why. This reduces the vacuum P_{in}, the resulting force drops and the surface tension closes the air inlet.

This design permits subtle adjustments of the d_1/d_2 ratio until small changes in the pressure difference between P_{in} and P_{atm} regulate the ink supply within such narrow variations so that no noticeable effect on the ink supply will be noticed by the writer.

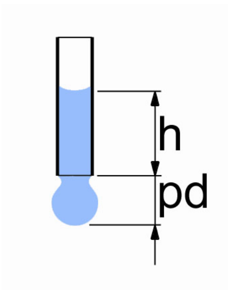

Figure 2.18: Pendant drop test

A hint for the capillary designer: An easy way of finding out whether a diameter is within the range of capillary action is testing the meniscus at the air inlet. If it curves concavely, towards the fluid, yes, then the design is within the range of capillarity, and the surface tension can hold the column of liquid. If it forms a semi-drop, when it curves convexly, away from the fluid, the situation is unstable and the design needs to be corrected.

To examine the effect of alterations, I used a measuring microscope to observe and measure the curvature of the meniscus at the lower end of a capillary. By now, you will certainly appreciate that the standardisation of the ink was absolutely crucial.

For calibration of the ink, I modified the standard pendant-drop-test, Figure 2.18, to suit my purpose, where I measured the drop size *pd* (length of pendant drop) at a constant capillary height h. In one go, I could test the characteristics of the ink with regard to capillary action and surface tension.

2.5.1 Applying to Fountain Pen

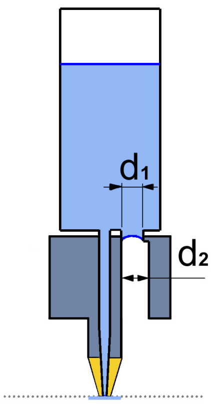

Figure 2.19: Simplified fountain pen

Figure 2.19 shows the progress towards the application of the above to the design of a fountain pen feed. The feed is in blue/grey and the nib depicted in gold. I have chosen a schematic display to explain the feed's function without the distraction of individual design features of the feeds of various manufacturers. I may come to this later on.

Now I will address the various functions of the feed and how they are carried out. Since we have focused on the air inlet, let's stay with that.

The air inlet needs access to the ambience, hence needs a vent which usually passes through the feed. There are reasons for the location of the air inlet near the reservoir; one is the height of the column of ink. You can see the abrupt crossover from d_1 to d_2 where the diameter of the air-hole d_1 which is suitable to hold the membrane, to a larger diameter d_2, which is still within the capillary range of ink. However, the meniscus forming at this cross-section is not stable enough to suit the standard function of the fountain pen. Through this significant change of cross-section, I can accurately determine the position of the meniscus

Let me repeat this core principle of controlling the direction and amount of ink and airflow in the feed: **Significant, abrupt crossovers in cross-section.** It applies for all functions where the direction of the ink or airflow needs to be switched, for example: directing the ink to the nib under normal circumstances or guiding the ink into the overflow chambers.

As I said, the primary purpose of the air canal d_2 is to provide air access into the reservoir through the feed. The increase of diameter from d_1 to d_2 prevents the air canal to be filled with ink under ordinary conditions. When ink is pushed out of the reservoir the surplus is taken up by the overflow chambers; only after they are filled, ink can enter into the air canal and as long as the fountain pen is not agitated, the ink will stay in there.

In my construction, the overflow chambers open into the air canal which not only achieves that they are completely filled but also assured the draining of the air canal in case ink has entered. As long as there is ink in the air canal no air can enter the reservoir.

The conical, yellow section in the diagram depicts the nib with its narrowing slit. The capillary forces are so strong that no ink comes off slit of the nib, under normal circumstances... Unless, it meets paper, which has a higher hygroscopic/capillary force than the capillary force in the nib tip.

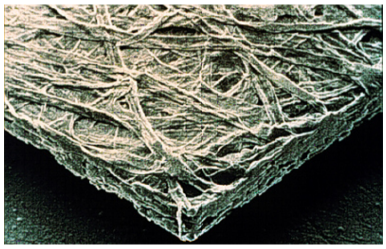

Figure 2.20: A piece of paper

Figure 2.20 shows a magnified piece of paper.

2.5.2 Overflow Slits or Fins

Another significant component of the feed is an array of slits or fins, often called the collector, arranged perpendicular to the axis of the feed. This is shown in Figure 2.21.

They are capillary slits arranged to absorb any excess supply of ink. (The causes for excessive supply I explain in the chapter on Temperature and Air Pressure). Via a distributor, the slits are connected with the feed capillary and vent into the air canal. Their capillary pull is less than the feed capillary, nib and paper, but higher than the air canal.

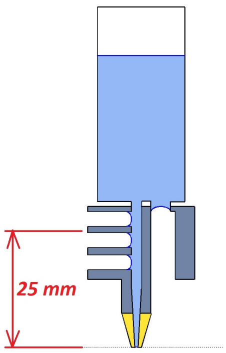

Figure 2.21: Simplified fountain pen – fill height of overflow slits

There is a decrease of capillarity in the feed, from the feed canal having the highest, a step lower follows the distributor, then the slits and lastly, the air canal.

Under normal circumstances, the ink remains in the ink canal and only wells from it into the marginally wider distributor when an excess of ink is loaded into the feed. After a further increase of ink volume occurs, the ink enters into the slits.

Due to gravitation, the slits fill one after the other, from the lowest upwards. The height of the filling of the slits is determined by the capillarity and the surface tension characteristics of the feed and the ink. I have tested many fountain pens in this regard. The maximum height I have observed occurred in my fountain pen and it amounted to a 25 mm from the tip of the nib, reliably, see Figure 2.21. I explained this in chapter Capillaries.

Marginally, this dimension can be influenced by the width of the ink feed capillary of the feed, however, if it is too narrow, the ink supply is reduced and may be insufficient. This is the reason why I put two ink capillaries in my feed design, namely, to create enough capillary pull and at the same time provide sufficient ink.

Now, that's when the balancing act starts. When a surplus of ink supply occurs, the capillary action of the overflow slits must take the ink away from the feed capillary before a noticeable variation of ink supply at the nib occurs.

Desirably, the capillarity of the nib and feed capillary is high enough so that the slits can fill before the ink drips off the nib. Since the slit closest to the nib experiences the highest hydrostatic pressure, it fills first, then those above it. As I mentioned previously, they don't fill simultaneously but from the bottom upwards. Hoping for supernatural participation, I added an extra slit to my feed design, just in case.

3 Simply Inks

During my early days of fiddling around with fountain pens (1978), I took ink as something given, just like air, gravity, or life. One does not question it but some recognise it as an essential part of existence.

Concerning the ink's chemistry, I found out that it had not changed since the 1920s or so. That's another reason for not to worry about it but to respect it and leave it alone.

When something remains unchanged for such a long time, it must be good. Another reason? At school or later university, chemistry had not been my favourite subject, more so, it didn't interest me the slightest but I got by and passed, just.

However, when I calibrated my test and measuring methods for the function of fountain pens I stumbled more frequently at unexplainable idiosyncrasies; fluctuations where I did not expect them, or they occurred in unpredictable variations. Inevitably the question arose: "Was the ink responsible for these variations?" Believe you me, I surely didn't like the sound of this question. It smelled of chemistry.

3.0.1 Setting up Ink Testing

After my first five-litre container of ink had emptied and I had started a new one, all previous test results had shifted in the same direction, sensible as well as the irregulars included. This aroused my suspicion that not all inks are the same. The easiest way of exploring this notion was to take samples out of several containers from the storeroom and compare them, not through chemical analysis but by applying a simple capillary test which would be much more relevant to my field of application.

From a local industrial glassblower, I acquired a bundle of glass tubes with inner diameters of 0.3, 0.4, and 0.5 mm, about 100 mm long. In order to find a ballpark figure, I measured the capillary rise with distilled water first and compared the results with the calculated values.

In the 0.5 mm tubes, the water would rise between 50 mm and 60 mm, tightly distributed around the calculated value of 56 mm. Of course, the smaller diameters gave higher readings but with a wider spread. Since the distribution of results proved to be wider and had not increased proportionally with the higher reading, I assumed impurities inside the capillary; they were much more difficult to clean.

How does one clean the inside of a 0.5 mm capillary? I had already learned that consistent, thorough cleanliness of all equipment was of utmost importance. Therefore, I heat-treated the tubes at 800 °C in our toolmakers' steel hardening oven. Then I pumped medical alcohol through the capillary to wash out the carbonised debris. A consecutive heat treatment dried out the alcohol for sure. Now I was sure there had not been any residue left inside, which could have affected the test results.

Then I measured the different inks, first of our supplier, the range of results of our ink was distributed around a mean value of 52 mm it showed a variation of ± 10 mm or $\pm 20\%$. It included the 56 mm value of water. This means the total variation from the lowest to the highest value was 20 mm or 40%, which had a huge influence on any test result when ink was involved. In order to achieve sensible, useful test results, I knew then that I had to brew my own ink with a variation of less than 4%, if not better.

Inks of other manufacturers and brands recorded a mean value at 45 mm and a variation of ± 15 mm (30-60 mm = 66.7%!). It also revealed that the inks of the world had a lower surface tension. Since the relationship between surface tension and capillarity is directly reverse proportional, the lower the surface tension, the higher the capillary rise. Applied to a fountain pen, the lower the surface tension, the wetter and runnier the pen writes.

Such ink is more readily absorbed by photocopy paper, in "normal" writing paper it wicks in more thus spreads more thus leaves a wider trace. It also dries faster, on paper as well as on the nib, the latter is a disadvantage which needs to be rectified through an extra-tight inner cap. More about this in the chapter Inner Cap.

As much as these findings fascinated me, I did not follow this path any further. It was too hypothetical. What I really needed to know at this point was,

3.0.6 Variations of Ink

Focusing on our ink, I compared the measurements of subsequent deliveries from our ink supplier and found variations of the surface tension of $\pm 12\%$, capillary action at $\pm 8\%$ and penetration speed of up to $\pm 12\%$. The drying time would not vary much at all, and the pH value was almost constant, it ranged from 6 to 6.5, which means slightly acidic.

At that time, I considered these variations considerable, however, the question about their significance on the workings of a fountain pen I could not answer. Therefore, the best person to ask was our ink manufacturer who had reliably and constantly supplied our ink for decades, as I had been affirmed by purchasing. I will write about this in the next chapter.

3.0.7 Measured contact angles of inks

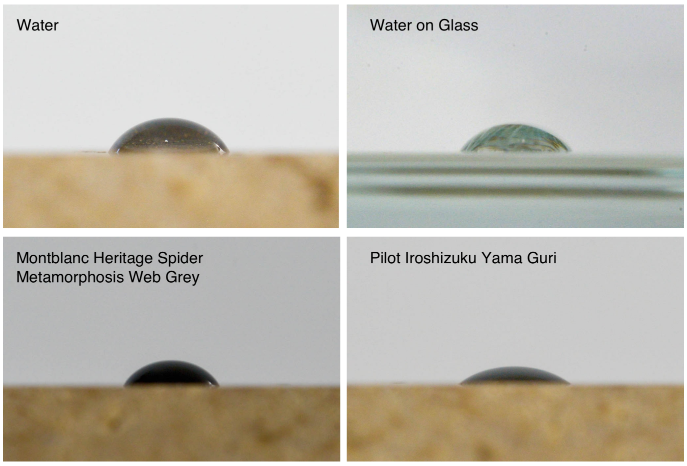

Figure 3.2: Illustration of the contact angles of water and ink on a horizontal piece of ebonite.

Jurin's Law (explained in Appendix 1) tells us that the force pulling a liquid through a capillary is proportional to the cosine of the contact angle. Therefore, the closer the angle is to $0°$, the greater the pull. This applies directly to the flow of ink through the capillary trough in a feed. So, in order to investigate the behaviour of different inks, their contact angles were measured using a rather old-fashioned, but simple method: you place a drop of liquid on a horizontal surface and observe the contact angle at the edge of the drop. In this case, a drop of liquid was placed on a piece of polished ebonite, and the angle was measured from a photograph taken with the lens level with the surface. An example of some of the results are shown in Figure 3.2, above.

I tested the following liquids:

- Tap water (on ebonite and glass)
- Lamy T52 Black
- Montblanc Heritage Spider Metamorphosis Web Grey
- Parker Quink Royal Blue (vintage)
- Pelikan 4001 Blue-Black
- Pilot Iroshizuku Yama Guri
- Watermans Washable Blue (vintage)

The results of the little experiment are listed below in Table 3.1. I've included not only the contact angles, but the cosine of those results so that you can get an idea of the differences between the inks.

Ink	**Contact Angle (θ)**	**cos(θ)**
Pilot	36°	0.81
Lamy	40°	0.77
Pelikan	43°	0.73
Parker	45°	0.71
Water on Glass	50°	0.64
Water	55°	0.57
Waterman	55°	0.57
Montblanc	60°	0.50

Table 3.1: Measured contact angles of various inks on ebonite.

So, for example, if we compare the two inks, with the most different contact angles, we find the following: the Pilot ink has a contact angle of 36° and the Montblanc, 60°. The capillary force is proportional to the cosines of these angles (also shown in the Table): 0.81 for the Pilot and 0.50 for the Montblanc. This means that, given the same capillary tube made of ebonite, the Pilot ink will travel 62% farther than the Montblanc (because 0.81 / 0.50 = 1.62 or 162%).

4 Nippy Nibs

For any pen, this is the point of action,
Ink is transferred to paper,
Its motion traces a lasting line.

Thought leads the course and its sequence, to meaning.
The focus of writer and pen maker merge,
Aiming for ease of writing.

The continuous line by the pen's obedience
Comforts the writer and frees the mind.
The pen maker has accomplished his task.

4.1 Introduction

4.1.1 The Magic about Nibs

Early nibs, pointy implements, were intended to fashion with some fluid (which would dry) detailed, contrasting marks on a surface with the intent to last. One could easily imagine them having preceded the invention of the wheel, surpassed only by the sharp edge of a splintered flintstone. Metal nib production is the oldest technology, definitely in the field of pens with the beginning of mass-production reaching back as far as the early eighteen hundred. This was, of course, long before the advent of fountain pens, at a time when a writer would fit the nib into a holder and had inky fingers.

At the time I went to school, that's how we learned to write with ink in the third year after we had left behind the chalk pencil on a slate and the pencil in a book with lined pages (before the eraser). Washing had become useless for our stained fingers, especially the thumb, index and middle fingers because they were so saturated with ink; and so was the timber of the desk around the inkwell.

More accomplished writers suffered from an aching longing of being able to write as long as possible before needing to interrupt the flow of writing, the flow of thought. I remember having nibs with small metal pocket attachments, which would hold a drop of ink by capillary force, which were often loaded with an eyedropper.

When I started investigating fountain pen production in the company where I was employed, the nib production people were the most unwelcoming, could I say hostile? They just did not want to tell me anything, not about the manufacturing, the reasons behind specific processes or the function of the nib. Their behaviour spurred my curiosity, my drive to find out their secrets. Being a congenital questioner is the innate prerequisite for being an ingeneer.

After a while, their behaviour gave me an inkling of the real situation when I suspected, they did not know as much as I thought. In conniving ways, I would ask them questions on fundamental ingeneering stuff pertaining to nibs, and their answers revealed their lack of knowledge. Or, maybe, they just did not want me to notice how antiquated their production methods were. Either way, they behaved as if they were the prima ballerina of manufacturing, and rightly so. Their nibs were world-renowned for form, function and durability.

Only later, after working with them when they ran into a problem which they couldn't solve on their own, I discovered, these manually highly skilled people deserved all my respect. However, before this happened, my attention was pulled towards some other pressing problems in another section of manufacturing. Nibs were working well, so I let them go for the time being.

During my research, I found a copy of an original article in the Scientific American about Nib Manufacture in 1879. I transcribed and annotated it; you may find the information as much insightful as I did.

4.1.2 The Function of the Nib

The nib has the task of putting the ink on the paper and finely controlling the ink supply. Ink flows when the nib touches the paper and stops when lifted off the paper. How does it do that without using a microprocessor, or as one would assume nowadays, an app on your mobile phone?

During my investigations on the function of the nib (as well as fountain pens), I found a few myths out there. As an ingeneer, those **irrationalities** make me smile and wonder where they originate from. As an artist, I can fully appreciate their value in solidifying an emotional bond between the user and their product. From this place, the original title of my website originated, **Fountain Pen Magic**; now I wonder why I have changed it.

4.1.3 The "Breather-Hole"

Traditionally, nibs had no hole. One can come up with several reasons which advocate a hole, however, in most fountain pen designs it has nothing to do with breathing, letting air into the ink reservoir. But then, one just never stops learning. After studying the feed of the Marukin Eyedropper of 1934, which has the air-canal on the top, the breather-hole does what its name says. Yes, some designs have a hole in the nib for breathing purposes.

In cases where nibs are combined with feeds having their air-canals below, the hole's primary function is to determine the end of the slit and hide inaccuracies during the slitting process. It firmly establishes a definite endpoint of the slit; its diameter influences the elasticity of the nib considerably. It also helps to position the nib in the jig during manufacturing.

Furthermore, it reduces the stress at the endpoint of the slit by distributing the occurring forces across a larger area. Slits ending without a hole may show fatigue stress cracks after some time.

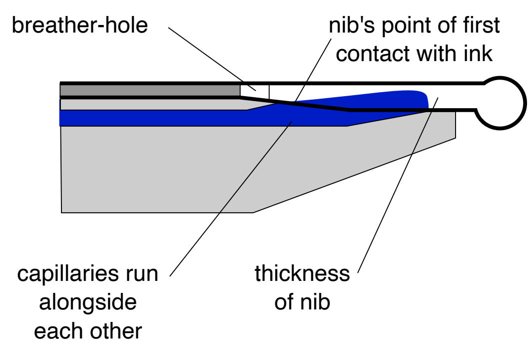

Figure 4.1: "Breather-hole" and feed cross-section

In Figure 4.1, I show the location of the "breather-hole" in good feed design. I have drawn a feed with a ducted ink canal where the ink is not exposed to air via the hole. If it would be, then the ink in the canal under the hole can dry out thus creating a plug, the end of all ink flow.

To mention it in this context: the breathing (allowing air to enter into the ink reservoir) is easier to adjust (during construction) and control during writing

4.2.4 Pressureless Writing

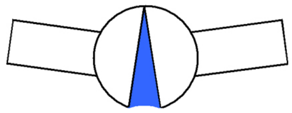

Figure 4.18: End-view of a nib

Using this expression indicates that you could move the fountain pen across the paper without the need of applying any pressure to the pen, and still, it would leave a line. I won't say anything about the quality of this line. This function is achieved by bending the tines at the tip so that the slit looks like an upside-down V, shown in Figure 4.18 where I have over-emphasised the angle.

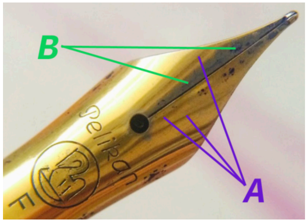

Figure 4.19: Inwardly-bent tines. The lines marked A show shadow lines of the normal curvature of the tines and nib.

The tines are bent inwards ever so slightly; you can notice this through the shadow lines radiating out from the breather hole towards the tip marked as B in Figure 4.19. The lines marked A show shadow lines of the normal curvature of the tines and nib.

Later, in the chapter on How to...for Nibs, I will explain this more in-depth around Figure 4.19. This process, the inward bending, is performed during the setting of the nib, which I describe in the article Nib Manufacturing in more detail.

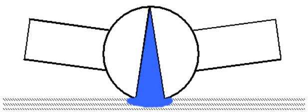

Figure 4.20: Ink meets paper

Explanation? Due to this geometry (turned over V), the slit capillary is kept open (against the pressure of pre-setting) hence, there is more ink available at the tip. Because the slit capillary is wider, its smaller capillary facilitates the crossing over to the paper.

It goes without saying, there must be enough ink to leave a trace without applying pressure, Figure 4.20. This pressureless writing is promoted by telling the user that it is less tiring and provides more comfort to the writer. Ask yourself: "What writer would use a fountain pen if they would want to write like this? Any old ball pen would do."

A more useful effect of the inward bent tines is that the time before the ink dries out is prolonged by a larger amount of ink available at this one part of the tip.

Once the pre-set pressure is overstepped the tines separate and deliver more ink to the tip. For sure, the width of the line is also influenced by the hygroscopy of the paper if the feed can supply the necessary ink volume.

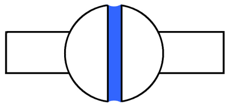

Figure 4.21: Fast-drying nib

Figure 4.21 shows a nib which is not set in the described way. Presumably, it would write normally, but when the pen is at rest the drying out occurs from both top and bottom, and therefore, faster.

When pressure is applied to such a nib, the slit widens on the top side more than on the side contacting the paper. This is highly disadvantageous because with more pressure the writer wants to draw a wider line which requires more ink and not less. When the ink supply cannot meet the demands of the paper, then the nib draws two parallel, thin lines using up the tiny bit of ink on the tip, an effect known as "railroading", demonstrated in Figure 4.22.

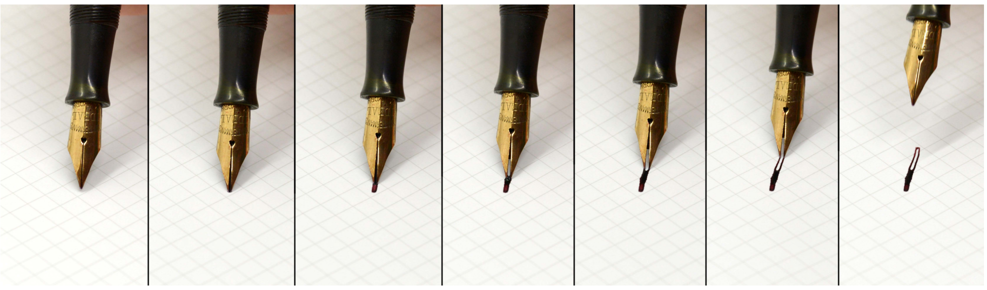

Figure 4.22: Railroading

4.2.5 More about the Slit

Let me refer back to our carboard roll nib where we noticed that the slit did not widen straight, in a V shape but rather curved. It is very pronounced in the real-life version: Figure 4.23, which I have shown already above for a different reason.

Figure 4.23: Still destroying a nib

Figure 4.24: A ruling pen, used for technical drawing

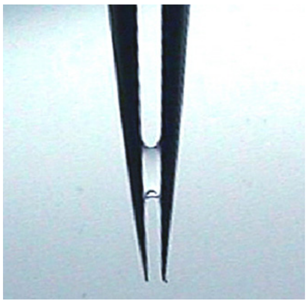

Figure 4.25: Water in tweezers

Exploring this situation is significant, because preferably, the capillary force, which pulls the ink towards the tip needs the slit to narrow towards the tip. In the old ingeneering days, we had special ruling pens, where the width of the slit was adjustable with a knurled nut.

If the nib was not clean inside the gap or the gap too wide the ink would not progress to the tip, Figure 4.25. The photo shows the tip of a pair of tweezers, however, the circumstances is the same. You can see the concave meniscus which indicates a small contact angle, hence a low surface tension and good capillarity. How to bring the ink to the tip? By gradually adding more ink at the upper end with an eyedropper.

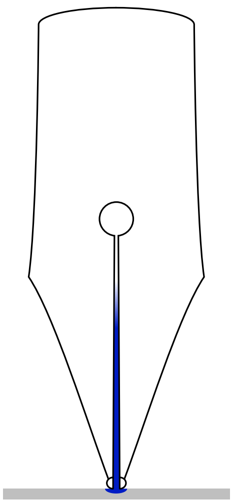

Figure 4.26: Nib meets paper

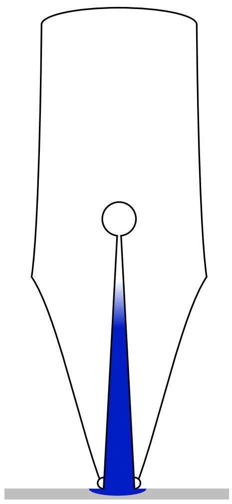

Figure 4.27: The paper pulls the ink from the nib

In the case of fountain pen nibs, we are luckier. In Figure 4.26, you see the starting situation, when the tip of the nib just touched the paper:

The slit is filled with ink; since its narrowing increases the capillarity towards the tip, and the ink is pulled forward. Then the ink crosses over to the paper because its absorption presents an even higher capillarity than the narrow slit of the nib.

The ink is absorbed by the paper. The compression of the paper fibres by the tip increases the capillary action and spreads the ink out, just a bit beyond the width of the tip, depending on the ink supply and more.

Figure 4.27 shows what happens when the slit widens extensively in a standard nib. As the tines open they bend and the opening of the slit curves.

Technically speaking the ink should retract like in Figure 4.25. However, the capillary attraction of paper is generally much higher than that of any metal (nib material); therefore, the ink does not retract. An explanation for this behaviour can be visualised by looking at the scenario from a bird's-eye view when we see a triangle-shaped membrane with two sides being formed by the tines and the third by the paper. Since the pull of the paper is so strong the membrane will remain as long as there is enough ink supplied by the feed and the geometry does not extend beyond certain limits or the nib is tilted.

I have advertised my Flex Nib section already several times. Some of the technicalities also belong here, but it would require rewriting, and I rather write about something else or go to the beach.

4.3 Material Technology

Participating in the various forums on the technical aspects of fountain pens and specifically nibs, I found, there is a lack of knowledge of the technical, physical properties of metals, those of steel and gold in particular. The words used are elasticity, flexibility, smoothness, comfort and more in a way as if they were interchangeable. Some are technical expressions of physics, others are terms of common language which are imprecise if one talks ingeneering language.

When we want to change the characteristics of a nib, then, as ingeneer, I want to know what the fundamental functional criteria of a nib are and where to apply my tools most efficiently. I also like to have a sense of what to expect.

I present here a condensed general ingeneering knowledge on the measurement and determination of the physical properties of metals. A more elaborate version can be found at Wikipedia[2].

4.3.1 The Stress-Strain Diagram

Figure 4.28[3] shows a fundamental piece of ingeneering information and learning to read it, gives a good sense of a material's behaviour and properties. It helps to explain the essential behaviours of many metals.

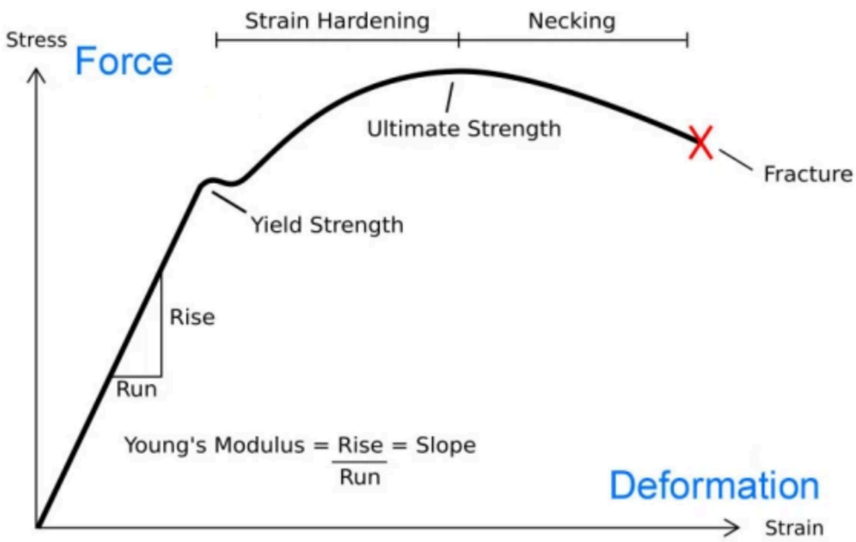

Figure 4.28: Stress-Strain Diagram

The two coordinates of the diagram are Stress along the vertical axis and Strain along the horizontal. Force applied across an area is called stress (in Newtons or pounds per area), while strain is caused inside a material due to deformation when an outer force is applied. Therefore, the same curve (stress-strain) also relates to the relationship of a force applied to a component and the consequential deflection.

The curve shows the typical shape of a ductile material such as soft steel. It can sustain significant plastic deformation prior to fracture. A brittle material, besides being often harder and needing higher loads for deformation, hardly enters the yield area, thus shows hardly any plastic deformation before fracture.

[2] https://en.wikipedia.org/wiki/Deformation_%28engineering%29
[3] ibid.

4.8.4 How to determine the length of bending?

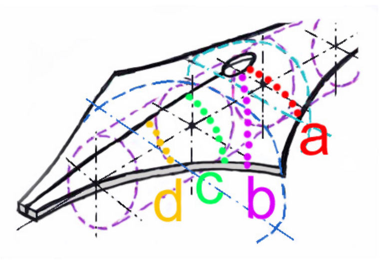

Figure 4.69: Nib radii vs. bending

It's a bit like: The chain breaks at its weakest link. They all look the same. How to determine, which one it will be? How to predict where the break will happen? In nib terms, we do not want the nib to break, but we want to be able to determine where and by how much the nib is going to bend.

The physics of bending I have discussed around 4.67, where we see that the curve is gradual, it isn't a particular, given line. As a basis for discussion, you can see in Figure 4.69 several suggestions for possible areas of bending. As a refresher: Keeping the force constant, the degree of bending is determined by the cross-sectional area along the line of bending where the cross-section area is the product of the thickness of the material and the length of the width of bending. The lines of bending I suggest could be at a, b, c or d.

Suggestion a

The width of the bending is shorter than in suggestion b; however, the radius of curvature is smaller (light blue); therefore, this section is stiffer, and bending will not occur there.

Suggestion b

Even though it presents the longest length of bending (distance from the tip, therefore longest lever and highest momentum) as well as a flatter radius (dark blue), the width (length of the purple line) is almost twice as long as in suggestion c.

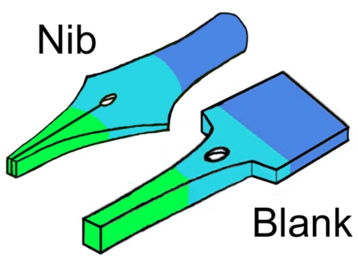

Figure 4.70: Nib rolled profile

Suggestion c

This is the most likely area of bending in this shape of nib. In comparison with a and b, it has a larger radius of curvature, and the width is narrower (the green dotted line). In Figure 4.70, you can see how the change in thickness and profile can move the bend area c further back because the thickness of material increases the necessary bending force by the power of 3. In addition, moving the bending area back also increases the length of bending.

Suggestion d

Why not this one, you ask rightly, the radius is the largest and the width the smallest, but the length of bending is very short. Remember, the length of bending effects the degree of bending by the 3rd power. Furthermore, the thickness of the material is often not constant, see again Figure 4.70.

The thickening of the nib around the length of the tines makes them stiffer, doubling makes them eight times stiffer. This has two advantages, at least. It shifts the area of bending further back; the longer the length of bending the more responsive the nib is, see Equation 4.12, the relationship is ℓ cubed.

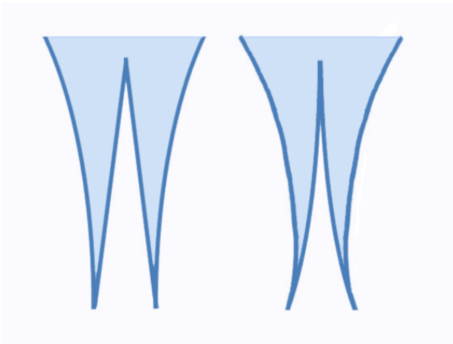

Figure 4.71: Tine separation affects capillarity.

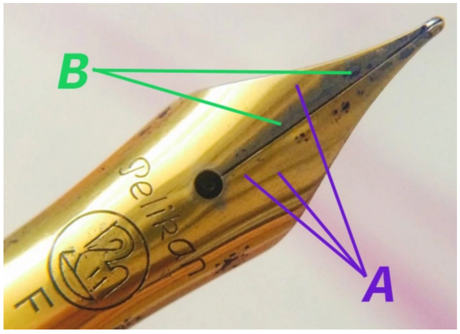

Figure 4.72: Reflection on Tines

The other advantage is that the slit opens with its sides being straight which evens the change of its capillarity, Figure 4.71. Hence, it prevents the retraction of ink. Bending the tines inwards has the same effect, as I have shown with the Pelikan nib in Figure 4.72; the (gradual) change of light reflection indicates the inwards curvature.

Summarising the information about the possible, most significant area of bending for this style of nib can be concluded to lay in the range as indicated in Figure 4.73 (the pink section), the location which I described in the suggestion (b) in Figure 4.69.

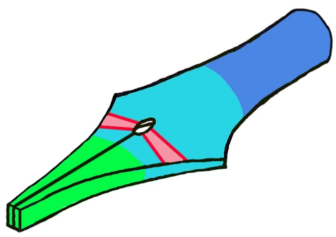

Figure 4.73: Area of Bending

This last chapter also demonstrates that there are many intervening aspects to consider, too many, to rely on mathematics and material technology alone, for sure, they are a good start. The feel for it comes with taking risks and making mistakes ignited by a passionate curiosity.

§

I feel a sense of saturation. It was a lot to digest for you. Tell me your questions, and I will continue expanding on this topic.

4.9 Flex-Nibs – Outline

This article has been inspired by the forum Experiments With Flex[7] on the Fountain Pen Network website. My ingeneer's mind was stimulated by the methodical composition of experimentation, and the valuable contributions by the visitors made this forum a lively experience. This motivated me to write this chapter.

4.9.1 Outline of Chapter

Let's start with an introduction to the structure of this chapter. After an initial discourse on the definition and classification of flex-nibs, I introduce the mechanics of nibs, with particular emphasis on flex-nibs. Then follow chapters on the practical application of such findings. Finally, I respond to visitors' comments on the forum when I consolidate their discoveries with ingeneering information.

A clear structure helps me to sort out where what belongs, and it helps you find what you are interested in. I added the titles to the sub-chapters underneath the summary.

Definitions of Flex

When reading some forums on the Fountain Pen Network, I noticed that there is a multitude of most romantic descriptive expressions for the various styles of fountain pen nibs, such as "Wet Noodles" and the opposite "Nail". Experienced flex-nib writers have surely a sense of the meaning, but I also noticed the confusion these expressions cause, especially amongst novices, like me.

- 4.10.1 All Nibs Flex (What is flex?)
- 4.10.2 All Nibs are preloaded
- 4.10.3 What's the Difference? (various writing scenarios)
- 4.10.4 Types of Flex Nibs (findings of the web)

[7] https://www.fountainpennetwork.com/forum/topic/324910-experiments-with-flex

Quantitative Classification

Here, I investigate and comment on two suggestions for classifying nibs according to their technical parameters. I conclude with a proposal of my own, with the hope that it will find the flex-writers' acceptance.

- 4.11.1 Technical Approach (Investigation and analysis of a test method)
- 4.11.2 Useful Line Width (How far can the tines be separated and the nib still produces a full line)
- 4.11.3 Useful Writing Pressure (Comfortable writing pressures)

Classification Proposal

A synthesis of what I learned from the above measuring methods including my own ponderings.

The Technical Side

This is an ingeneering approach to the function of flex-nibs, an introduction to the principles of the mechanical physics of bending, the nib's shape and material and the suggestions of expressions on nib characteristics. You may be aware of the chapters on standard nibs pertaining to these topics. Nib Materials and Nib Mechanics.

- 4.13.1 When one applies Sufficient Force (... anything can be bent, Force vector diagrams on nibs)
- 4.13.2 Spreading of Tines (Why do the tines open when force is applied to the tip of the nib?)
- 4.13.3 Bending (Basics on bending)
- 4.13.4 Bending of a Profile (about bending moments and the effect of shape)

More Technical

In this section, I apply the basics from the above chapter (the technical side) to the characteristics of nibs as they are determined by their dimensional details. Comparisons are made between nibs after their dimensions have been calculated or graphically established and their actual behaviour when attached to a fountain pen.

- 4.14.1 Variation of the Theme (application of the basics on dimensionally detailed nibs)
- 4.14.2 Permanent Damage (A refresher on Stresses and Strains)
- 4.14.3 Nibs are not flat (discussion on the effect of curving a nib)
- 4.14.4 Effective Dimensions (How to establish the dimensions, which influence a nib's performance.)

Flex Nib Modifications

As the title suggests, here I respond to some technical discussions in the forum on Experiments With Flex. They cover aspects of adding or increasing the breather hole or adding scallops to the side of nibs. I also include here a discussion on the function of flat tines.

- 4.15.1 Increasing the Breather Hole
  - Wing Scallops
  - Long Slit and Breather Hole
  - Radius of Nib Curvature
  - Thinning Nib
  - Shape and Position of Scallops
  - Mating Nibs and Feeds
  - Underside of the Nib
- 4.15.2 Hole versus Scallops (What's more effective?)
- 4.15.3 Flat Tines (Samples of flat nibs, how they work and how beautiful they are)
- 4.15.4 In Summary
- 4.15.5 Finale (Thanks and acknowledgements)

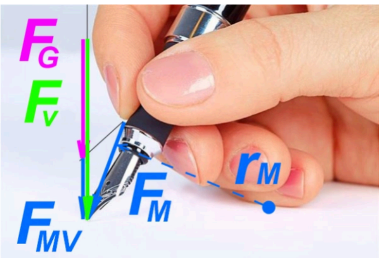

Figure 4.91: Isolated Forces on a Nib

Now, let's apply our new knowledge to the situation of a fountain pen as shown in Figure 4.91. The active, vertical force for writing is F_V. It is the sum of the forces F_{MV} and F_G. They can be merely added because they act along the same line of action.

Wait, don't panic: The forces F_{MV} is the vertical component of the force F_M, the tangential force caused by the momentum with the radius r_M around the point where the hand rests on the surface. The force F_G is caused by the weight of the unsupported part of the hand and the weight of the pen. That was not too hard?

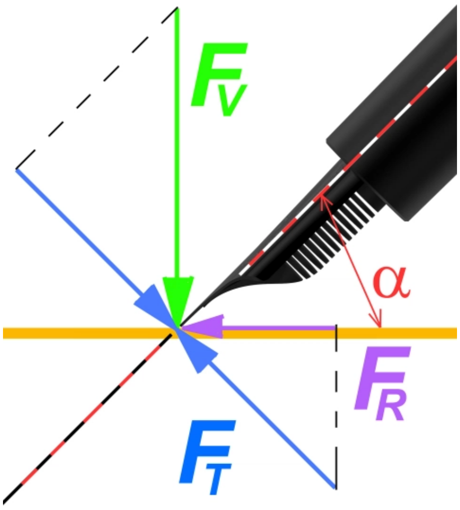

Figure 4.92: Force Diagram of Nib

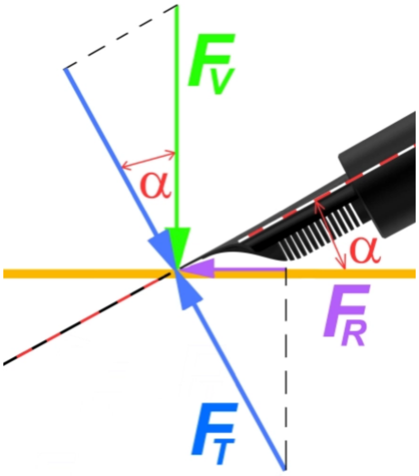

Figure 4.93: Fountain Pen in low Position

Figure 4.92 shows how the vertical force F_V is split up into F_T, the force which acts to separate the tines and F_R, the force needed to overcome the friction between nib tip and paper.

Let me point out something, which is already well known by experienced flex nib writers: "When you reduce the angle α between pen and paper, the nib responds more readily to writing pressure variations."

Figure 4.93 demonstrates this, it is a variation of Figure 4.92. You can notice that with the same vertical force F_V but a reduced angle α the tine spreading force F_T increases. Simultaneously, the the friction force F_R reduces. For the technically minded: F_T increases with the cos of α while F_R reduces with the sin of α.

$$F_T = F_V * cos(\alpha) \tag{4.6}$$

$$F_R = F_T * sin(\alpha) \tag{4.7}$$

$$F_R = F_V * sin(\alpha) * cos(\alpha) \tag{4.8}$$

As I said, this is not an unknown fact; here I offer a technical explanation. In the picture, you can see that the thickness of the feed is a limiting factor.

Ingeneers of fountain pens for flex nibs have catered for this and reduced the thickness of the feed as can be seen in Figure 4.94, thus permitting the pen to be tilted even more, as shown in Figure 4.93.

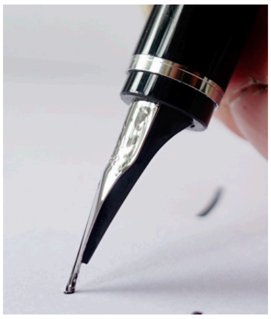

Figure 4.94: Good Design

There are more good things to say about this construction and the nib, and I will return to it later, more than once.

4.13.2 Spreading of Tines

After we isolated the forces acting on the tip of the nib let's have a look at how they separate the tines. Why? Isn't it obvious? It appears obvious, but you sense already, there is more behind it than meets the eye.

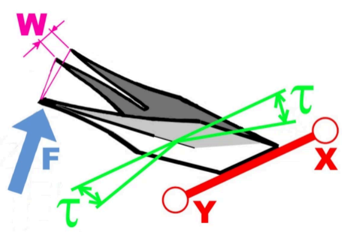

Figure 4.95: Simplified Nib Geometry

I have written already about the reason why the tines open in the chapter about Nib Mechanics; therefore, I only repeat what is necessary to know with regard to flex nibs. Let's just quickly recapitulate, adhering to the old motto: "Repetitio est mater studiorum."

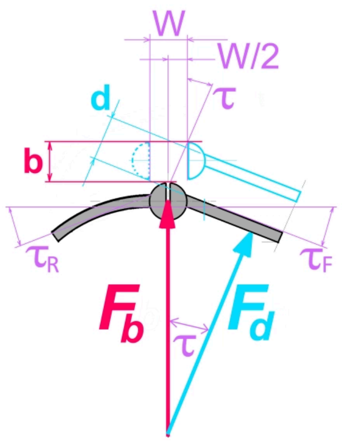

Figure 4.96: Nib Separation and Forces

In Figure 4.95 I show a simplified nib. The opening of the tines is a consequence of the nib being bent (during manufacturing) by the tine angle τ along the axis in line with the slit. Cut out a model from a piece of paper and play with it. You can see that increasing τ results also in an increase of W even though the deflection of the tines is the same. Good thought, however, there seems to be always a “however”...

Figure 4.96 is an ingeneering drawing showing the geometric relationship between dimensions. The vertical bending caused by the force F_b by the amount b applies the $F_d = F_b * cos(\tau)$ onto the tines which results in the deflection d of the tines as follows:

$$d = \frac{b}{cos(\tau)} \tag{4.9}$$

meaning that the tine deflection d increases more rapidly than the amount of bending b due to the leverage of $cos(\tau)$.

The widening of the slit follows the equation:

$$\frac{W}{2} = b * tan(\tau) \tag{4.10}$$

or

$$W = 2b * tan(\tau) \tag{4.11}$$

Again, the larger the angle τ, (the tilt angle between the tines) the wider the gap between the tines at the same angle of bending.

The benefit of this geometry sounds promising, however, when considering the forces, it does not look quite as bright. Now, it is the other way round. Force F_d reduces by $cos(\tau)$. Or in other words, the larger the angle τ, the more a nib resists to opening the tines.

Furthermore, approximating the radius to a straight line is somewhat mislead-

Consequently, although latex is still used in ink sacs, particularly for the restoration of older pens, other materials such as silicone and PVC have been introduced over the years to avoid these problems.

Although the core component of a filling system with a flexible bladder is the sac itself, the remaining discussion is about the surrounding mechanism that is used to squeeze it when filling.

The first step in using a flexible sac to pull in ink is to collapse it, and this can be done either pneumatically (using compressed air) or mechanically (by squeezing it with an object).

7.3.1.1 Pneumatic systems

When a flexible ink sac with an outlet (through the feed) is placed inside an air-tight container (the barrel of the pen) and the pressure of the air inside the barrel is increased, the latex bladder collapses, pushing air out through the section and feed. The only question is how to apply the increase in air pressure inside the pen barrel. There are three common methods for doing this:

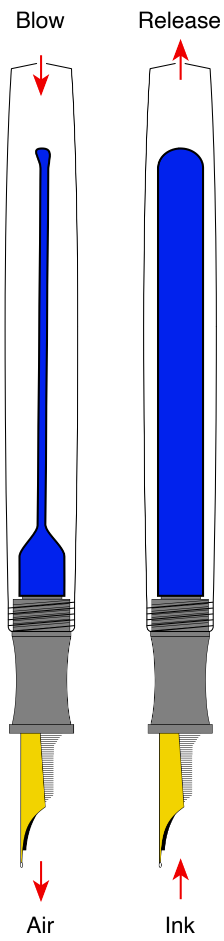

Figure 7.4: Blow filler

1. Blow Filler

A blow filler pen is possibly the simplest self-filling mechanism. The barrel and section form an air-tight seal, and a small hole is drilled in the end of the barrel. In order to fill the pen, the user:

- submerges the feed into the ink
- blows into the hole, which increases the air pressure inside the barrel, squeezing the ink sac, and thereby evacuating the air inside it through the section and feed.
- When the seal around the hole is broken, the excess air inside the barrel escapes, the ink sac returns to its original size, and ink is pulled into the sac.

10 Appendix: Jurin's Law

10.1 Surface Tension Revisited

Pure water is comprised of only two elements: oxygen and hydrogen. These atoms are held together because they share electrons in their outer shells, forming a very tight bond, and resulting in a group of two Hydrogens atoms locked to one Oxygen atom, hence the "formula", H_2O.

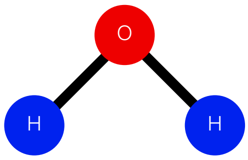

Figure 10.1: Water molecule

When two or more water molecules are located near each other, there is a weak *electrostatic attraction*[1] between the oxygen atom in one molecule and a hydrogen atom in an adjacent molecule. This attraction, known as a *hydrogen bond*, causes the molecules themselves to be slightly attracted to each other, resulting in a larger effect called *cohesion*. This results in the tendency for water to "clump". Watch a water drop running down a window pane: when it comes near another drop, they will suddenly merge into one bigger drop. This is a visible result of that cohesion.

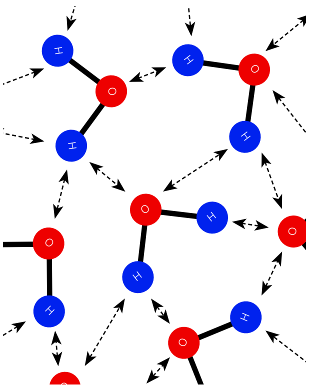

Figure 10.2: Hydrogen bonds between adjacent molecules shown as dotted arrows.

[1] "electrostatic" attraction is a force caused by differences in electrical charge between two things – where one object has too many electrons (and therefore has a negative charge) and another has too few (and therefore has a positive charge). This is the same force that causes your hair to be attracted to a ballon.

That cohesion is also the reason a water drop, falling in air, will try to stay together; and, since all of the molecules are equally attracted to each other, they tend to form a sphere, so that all those forces are equally distributed throughout the entire drop. (If you've read the Chapter 2, it should not come as a surprise to find out that raindrops, while falling, are not "raindrop shaped" but spherical. This is why spherical shot for guns was originally made by pouring lead from high towers like the one in Figure 2.4 on page 22.)

Figure 10.2 shows a small group of water molecules, held together by the hydrogen bonds between them, shown as dotted arrows. In this case, I've drawn a small portion of a larger amount of water, so the hydrogen bonds are all pointing in different directions, and they are all roughly equal in strength, since each molecule has the same number of adjacent molecules to be attracted to.

However, if you are on Earth, and if you don't have an infinite amount of water, (both of these conditions are very probable) then it will have a surface somewhere. Let's look at what happens at the molecular level where the water meets the air.

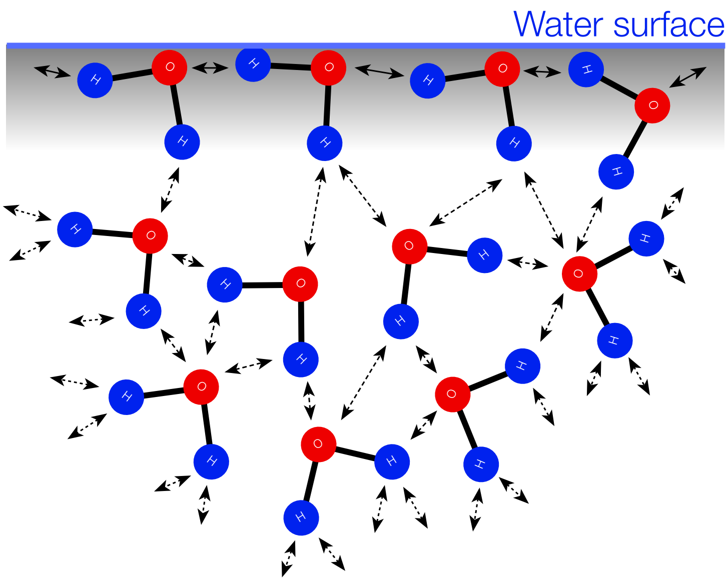

Figure 10.3: The hydrogen bonds between the molecules at the surface (the grey area) are stronger, forming a "skin".

At the surface of the water, the last "layer" of molecules have fewer adjacent molecules to be attracted to, because there are none above them. In this layer, the hydrogen bonds between the molecules are stronger, since they don't have to "share" the forces with as many molecules as the ones deeper in the water. This is shown in Figure 10.3 as solid arrows in the grey area near the top.

That extra-strong attraction is called *surface tension* which forms a kind of "skin" on the surface of the water. If you then have something small and light enough (like an insect or even a very small rock), it can rest on the surface of the water without breaking that skin. It's a little important to understand that this is not the same as an object floating *in* the water (where the water is displaced by the object, like wood, a duck, or a witch for example). The object is resting *on* the water's surface.

10.2 Contact angle

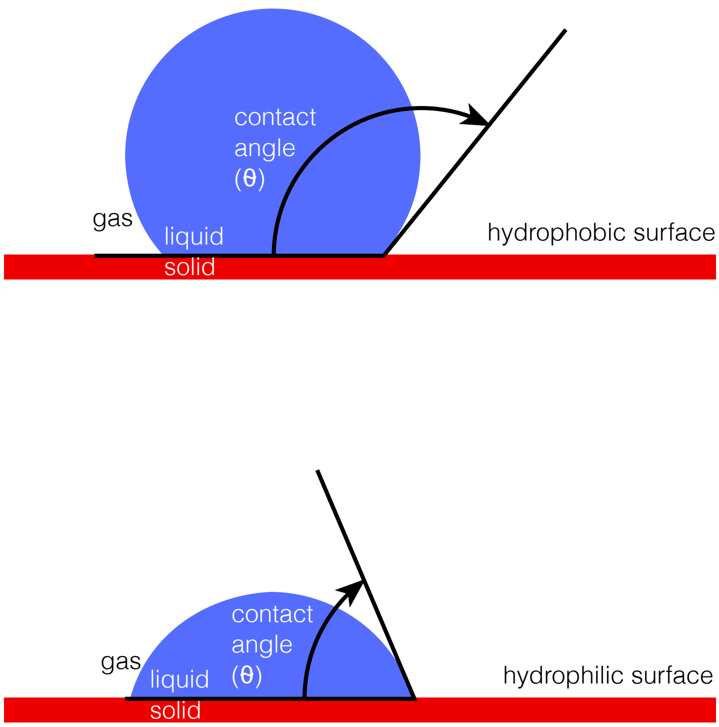

Figure 10.4: The contact angles of the same liquid, shown on two different horizontal surfaces.

The electrostatic attraction between adjacent water molecules produces the cohesion that, on a human scale, causes waterdrops to hold together. However, the same water molecules can also be attracted to other substances. For example, there is an attraction between water and glass, seen when a rain drop is "stuck" on a window pane. The same forces that hold the water drop together hold the drop itself to the glass. However, when we're talking about a

11 List of Abbreviations

A	cross-sectional area
b	vertical bending
$b1$, $b2$	line of bending
C	Celcius
d	interior diameter of capillary tube
g	acceleration due to gravity
h	height
I	moment of inertia
E, E-Mod	modulus of elasticity (Young's modulus)
F	force, clamping force
F_D	vertical force downwards
F_H	horizontal force
F_U	vertical force upwards
F_V	vertical force
K	Kelvin
r	radius of a circle
RI	rigidity index
ℓ	length
m	metre

m	mass (note that, when m denotes mass, it is italic)
N	Newton
p	pressure
Pa	Pascal
pd	length of pendant drop
ppm	parts per million
r	radius
R	gas constant
s	separation (e.g. tine separation)
S	local angle of (rough) surface
t	thickness
T	temperature
V	volume
W	width

α	angle of pen relative to surface of paper
γ	coefficient of surface tension
γ_{la}	coefficient of surface tension of a liquid in air
δ	deflection distance
ζ	angle of scratches in rough surface
Θ	contact angle
ρ	mass density
σ	spring constant
τ	tilt angle between tines of nib
ϕ	angle of edge holding nib on section

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