by Pete Jermann

Spine Control

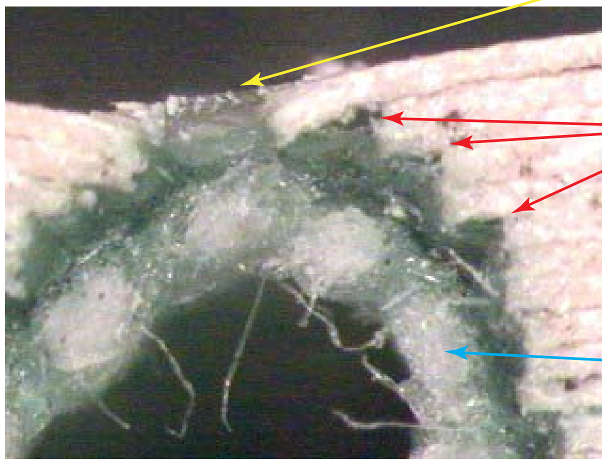
In Reflections on Book Structures -Part *2 I discussed glue line failures. This article looks at the physics of the spine and the means by which it is controlled, whether intentional or unintentional. Understanding the physics of the spine and its effect on the glueline or point of leaf attachment contributes to better book design. The need for and the amount of control required is predicated on the understanding of glue line failures and the concepts of "pull" and "peel'" stresses discussed in part 2. Though my focus is on fan-glued bindings, the principles and methods discussed lead to a better understanding any kind of binding, whether it be sewed or glued.*

A good story frequently begins with a good picture. When I wrote the section in part 2 on "Reflections on the Glueline" I illustrated with diagrams what I could see through the microscope. With the cooperation of a biology professor at the local university, I recently secured the use of a digital microscope and took pictures of the glueline in two sample books, one comprised of uncoated paper and the other comprised of coated paper. These pictures both confirm and add to the diagrams I presented in Reflections- Part 2. Both pictures were taken on textblocks lined with a single liner and glued with a very elastic glue (colored with green food coloring to make it more visible) The textblock opened fully flat such that the spine folded back on itself. ***The need for spine control, when we need it and how much we need grows from an understanding of what these two pictures show.***

To quickly review the discussion in *Reflections on Book Structures - Part 2*, the glue bond between uncoated papers remains intact as the leaves split internally and expand to the arc required by the opened book. As some give is always required at the point of opening, this break-in is ideal and does not affect the durability of

A Microscopic View of a Fanned Glueline

Coated Paper



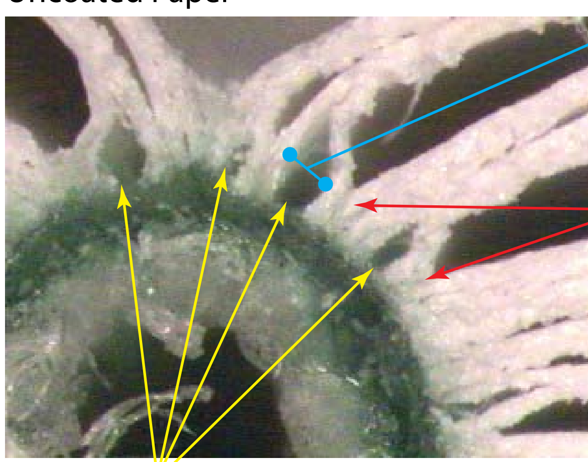
The bond between the opening pages has broken, and the glue line has spread to expand to the arc required by the tight radius.

Adjacent pages have blocked in groups of two or more pages. As the pages shift to conform to the arc of the opening, the bonds between the pages in the different blocks have already broken.

End view of the threads in the super (68 x 68 thread count). The weave of the super is loaded with the pva, integrating it into the glue layer.

Notice the elasticity of the glue (colored green with a bit of food coloring to make it more visible) which moves and forms with the pages when the book opens. **The glue is visibly a dynamic, unique layer with its own characteristics rather than simply an invisible bond between the leaves and materials making up the spine.**

Uncoated Paper



Notice that the point of maximum expansion, signified by the widest point of the split, is at the inner edge of the glueline.

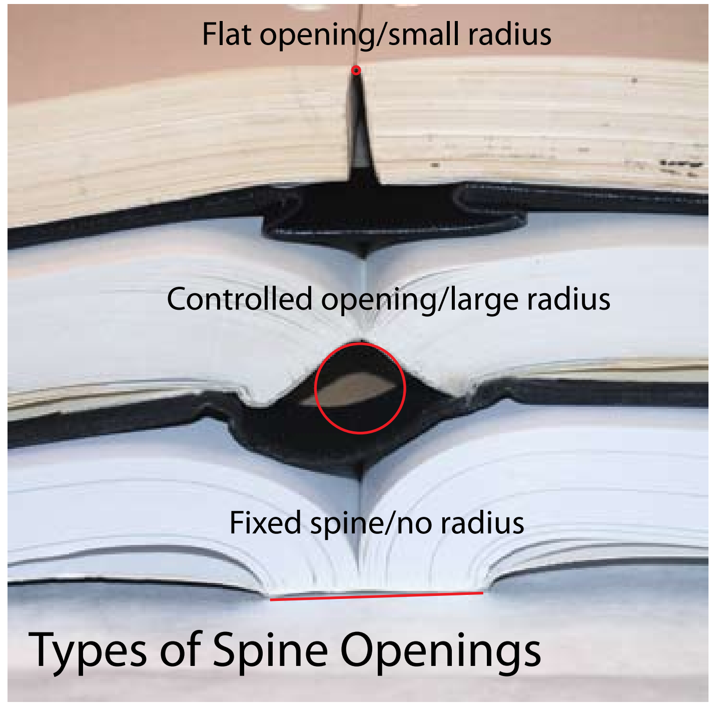
The bond between the pages remains intact.

To accommodate the expansion required by the tight opening radius, the pages split, allowing the glue line to expand to the required arc.

the book. However, the bond between adjacent leaves of coated paper fail where the coating and paper meet. The glue is not the problem. The paper is the problem. When a book opens fully the joint between the pages is subject to peeling forces. Whereas glues with adequate adhesion and elasticity are readily available, the inelastic adhesion between the coating and the paper easily peels apart. This negates and overrides any advantages the glue may offer. This is a case where we want to design to the stronger pull strength, rather than the weaker peel strength, of the adhesive bond between the coating and the page. By controlling the motion of the spine, we prevent the peeling forces from coming into play. This strengthens our page attachment allowing it to better resist pulling forces the leaves may be subjected to when the book is used.

An article on "spine control" should begin with a definition. Spine control is the ability to determine how much the spine flexes when a book opens. Frequently, as with many commercial hotmelt bindings, the process, rather than the needs of the particular book, determines the amount of control. In many cases the result is a fixed spine, one that does not flex at all. Most of these books fail the reading-while-eating-lunch test as holding the book open requires the same hands you need to eat your lunch. While a fixed spine is the easiest path to a durable book, it is also the least user friendly unless it is blessed with large margins and a paper that drapes very well. Many books would benefit from a flexible, more user-friendly spine.

Let me start by establishing a terminology to describe three degrees of spine control. When we open a book the spine flexes into an arc, either along its entire width, along a finite part of its width or not at all. The spine of a book that opens flat to the middle will take the shape of a hairpin with the opening at the head of the hairpin. The radius of the opening is quite small and barely perceptible. However, under magnification it is evident that no matter how tightly the spine turns back on itself there is a small arc at its apex. This ***flat-opening*** book with an arc of an often imperceptible radius represents our first category of spine control. At this level there is essentially no control. Our binding structure is designed to not impede movement of the spine in any way. This creates the most user-friendly book and represents an ideal most binders would probably like to achieve. However, achieving a durable, flat opening with an adhesive binding requires excellent adhesion



with an elastic glue, a condition that is hard to achieve with some papers, particulary coated papers. The second level of control I have chosen to call a ***controlled opening***. In these books the motion of the spine is controlled such that it flexes into a fairly even arc across the spine. The radius of the arc may vary, but there is enough structure, by design or happenstance, to prevent a flat opening. The third level of control is the ***fixed spine***. As a flat-opening spine essentially represents no control, a fixed spine, conversely, locks the spine flat and prevents any movement at all.

So, why do we need to control the spine and at what level? A fixed spine produces a durable but, frequently, lousy book as the reader must dedicate himself to holding the book open and can only despair should the need arise for a decent copy or scan. Forcing a book with a fixed spine into a more compliant attitude tends to actually damage the book such that the spine actually breaks or assumes an attitude that now prevents it from closing properly. However, for very thin books, providing they have an adequate gutter margin and a paper that drapes well, a fixed spine is often the best solution. On the other end of the spectrum, the flat-opening book answers well to useability and can be durably constructed with many uncoated papers. However, there are instances where a flat-opening binding simply cannot be durably constructed with either the materials the book demands or the materials presented to the binder.

Usually these are coated papers, but they may also simply be papers that drape poorly. In between the fixed spine and the flat opening spine, the controlled spine is an attempt to find the best compromise between durability and useability. The amount of control varies with the paper and the thickness of the book. The goal is to add control sufficient to prevent the failure of the bond between the pages.

At the beginning...

When we start with a loose stack of the pages that will comprise a book, we start with total freedom of motion. The pages can be opened flat or separated at will. As soon as we consolidate the pages into a textblock this freedom of motion changes. From here on out every step in the binding process from adding glue to lining the spine to building the case has the potential to further limit that freedom. The key to achieving the required amount of control is in understanding what you want to achieve and how each step affects that goal. ***Two major structures affect the motion of spine; the construction of the textblock's spine and the construction of the cover or case.*** I will address the spine's structure first.

The finished spine of a textblock is a laminate, a layering of various materials, beginning with the book leaves themselves and building out with glue and various liners. Let me start with the paper that makes up a book's leaves.

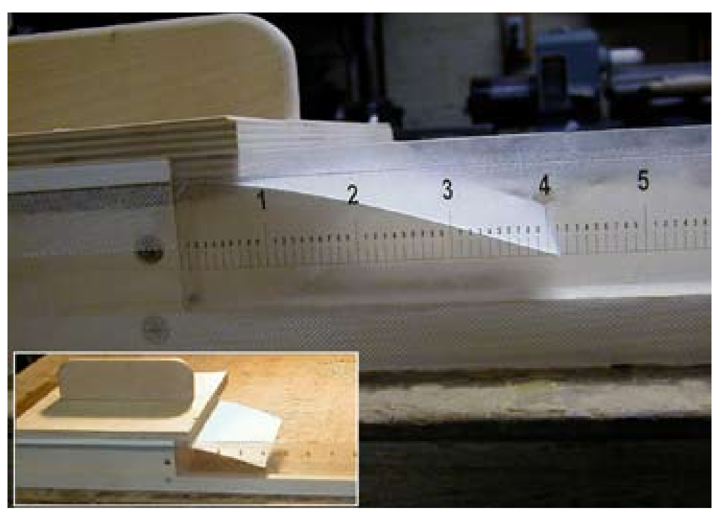
Paper

A book begins with paper. It is paper that makes up the pages that give the book its purpose. Books are printed for many different reasons and for many different intended effects which, in turn, leads to many different papers with many different characteristics. ***It is the paper which determines the binder's possibilities***. With a proper binding structure most any paper can be successfully bound into a useful and durable book. With the wrong binding structure most any paper can produce a book bound to fail.

The paper making a book's pages is the most important component of the spine. The paper sets the criteria for a book's structure. Paper has three defining characteristics which contribute to and affect the development of the spine structure, its 1) drapeability (my own term) 2) its adhesibility and 3) its cohesivesness or how it gives internally under stress. Drapeability refers to a paper's ability to naturally fall or drape into the gutter margin of an opened book as opposed to leveraging away from the margin. Very loose, floppy or drapeable papers easily flex into the margin. These papers tend to produce books that "flop" open easily regardless of binding, whether it be sewn through the fold, sidesewn or adhesive bound. Less drapeable, stiff papers tend to remain noticeably erect when a book is open or require noticeable force to fully open a book to a readable position.

Drapeability is an indicator of how much leverage a paper is capable of exerting at the glue line. A paper's drapeability can be measured on a relative scale. I constructed a fairly simple device (see illustration below) that measures what I refer to as the drape factor. The drape factor is determined by the number of inches a paper extends from an edge until it drops one inch at the leading edge. The measurement itself I express in tenths of and inch. Hence if a paper extends 3.2 inches before it drops one inch it has a drape factor of 32. For purposes of comparison a typical page of a current National Geographic has a drape factor of 34, a page in Time Magazine a drape factor of 24, and a piece of 10 pt bristol (paralell to grain) a drape factor of 57 and (crossgrain) a drape factor of 72. These drape factors represent single unglued sheets of paper. Any edge cockling significantly increases the actual drape factor of any paper at the glue line.

Drape factor gives us a relative means of comparing the potential energy different papers can exert on the glue line. The higher the drape factor the greater the potential energy if the pages of a book are constrained when opened.



Drape Gauge

This energy is potentially destructive. The binder can either counteract it by by controlling the spine or dissipate it by letting the pages move freely into a flat opening. A high drape factor (stiff) paper challenges the binder. He or she can design a book that either resists the built up potential energy or dissipates the energy. Should the binder choose the path of resistance, he/she must make sure the resistance is sufficient otherwise the binding will self destruct. The higher the drape factor the greater the amount of control required. Should the binder choose to dissipate the energy rather than control it he/she must ensure that in doing so the durability of the binding is not unnecessarily compromised. The path the binder takes is dependent both on what the binder expects of the finished product and other characteristics in the paper that may force him or her to compromise between what is desired and what is achievable.

The other characteristics of a paper that affects its bindabiliy are its adhesibility (its ability to successfully bond with an adhesive) and it's internal or cohesive strength (ultimately defined by how it gives into stress). As discussed previously, uncoated papers tend to split internally, whereas coated papers tend to give between the coating and the paper substrate (the paper lacks cohesive strength). If the substrate is highly cohesive then failures may be solved by increasing the adhesibility of the glue. However, if the paper substrate fails, as is frequently the case with coated papers, a more adhesible glue will not solve the problem.

In summary, when we begin building our book we are confronted with three questions. Does the paper drape well? Will our adhesive bond well with the paper? And, will the paper itself remain intact when subjected to the opening stresses of a book? Before looking at the structures that might answer the combinations of answers we receive from the above questions, we need to understand the other components of the book, beginning with glue.

Glue

Glue can be made of many different substances for many different reasons and to achieve many different effects. Understanding glue requires seeing it as more than a simple bonding material but as a unique layer in the structure of the spine. Just as we would consider that a piece of paper lining the spine would act differently than a piece of cloth or vellum we need to understand that different glues will have different effects. These structural effects tend to be within the film the glue forms rather than in the actual bond with the substrate.

Assuming adhesion is sufficient, which is the case with most glues used in bookbinding, the qualities of glue that affect our book structure are flexibility, elasticity and thickness. For a glue to be useful as an adhesive on a book's spine, it must be flexible so it can move with the spine when the book opens. If it is not flexible the glue will crack. Many of us have seen old paperbacks that literally crack when opened. My guess is that these books were not intentionally made this way but were functioning books made with a flexible glue that became brittle with time. Without flexibility a book will break in use.

Elasticity is the ability of the glue to stretch and return to a previous state like a rubber band. Whereas a piece of paper is flexible we would not characterize it as elastic. Most glues we use in bookbinding are flexible, but many are not very elastic. I will refer to glues that are flexible, but not so elastic, as ***stiff glues*** and the more elastic ones as ***elastic glues***.

The ability to build thickness is the third characteristic that affects its ability to control the spine. Some glues have more solids and build thicker films. Hotmelt glues that depend on heat and cooling to apply rather than the evaporation of a solvent can easily build to a substantial thickness.

So how do these characteristics make a difference? A stiff glue will tend to control the movement of the spine more than an elastic glue (see illustration on page 5). For any given glue, the thicker the glue film the more it will control the spine. If you are designing a book to open flat with a minimal radius at the point of opening you need a glue that is elastic. On a microscopic level there is significant dimensional change at the point of such an opening. A stiff glue simply cannot accomodate the dimensional change. Viewed under a microscope an elastic glue visibly gives (think of a wad of gum on the bottom of your shoe pulling away from the pavement). As long as the elastic limit is not exceeded the glue returns to it initial shape. This cycle can be repeated indefinitely if the glue is sufficiently elastic. If it isn't it will fracture and fail either immediately or over multiple uses.

So why choose a stiff glue over an elastic glue? Because basic physics requires a compromise. We can't have both elasticity and brute strength. An elastic glue must give in order to stretch. At some point it will stretch to the point of failure. Its cohesive strength is lower than that of a stiffer glue. In page pull tests elastic glues yield before stiffer glues. A stiff glue has stronger cohesive strength, resists stretching and requires a greater force to produce failure. The binder must decide between the need to give and the need for more strength. Generally speaking, a binding that opens flat requires the give of an elastic glue. If our book is to be more controlled a stiff glue will both strengthen and add control to the spine.

In addition to the elasticity and flexibility of the glue the thickness, or depth, of the film affects the movement of a book's spine. With cold emulsion adhesives, such as the PVAs frequently used on bookbinding, the binder seldom uses thickness to control the spine. These adhesives dry relatively slowly and require many layers and much time to build up a controlling thickness. Such is not the case with hotmelt adhesives where thick layers can be quickly applied as cooling is all that is required for the glue to cure. Whereas books bound using PVAs require futher measures to ensure control of the spine, books bound with hotmelts can achieve control simply by controlling the thickness of the glue. This is evident in many paperback books bound with stiff hotmelt adhesives. You can remove the covers from many of these books and the spine will remain stiff. This is a function of both the fact that these glues are generally stiff and because, compared to a PVA emulsion, they are quite thick. They resist the movement of the spine without the additional measures (liners, case control, cords, etc.) that a PVA binding may require.

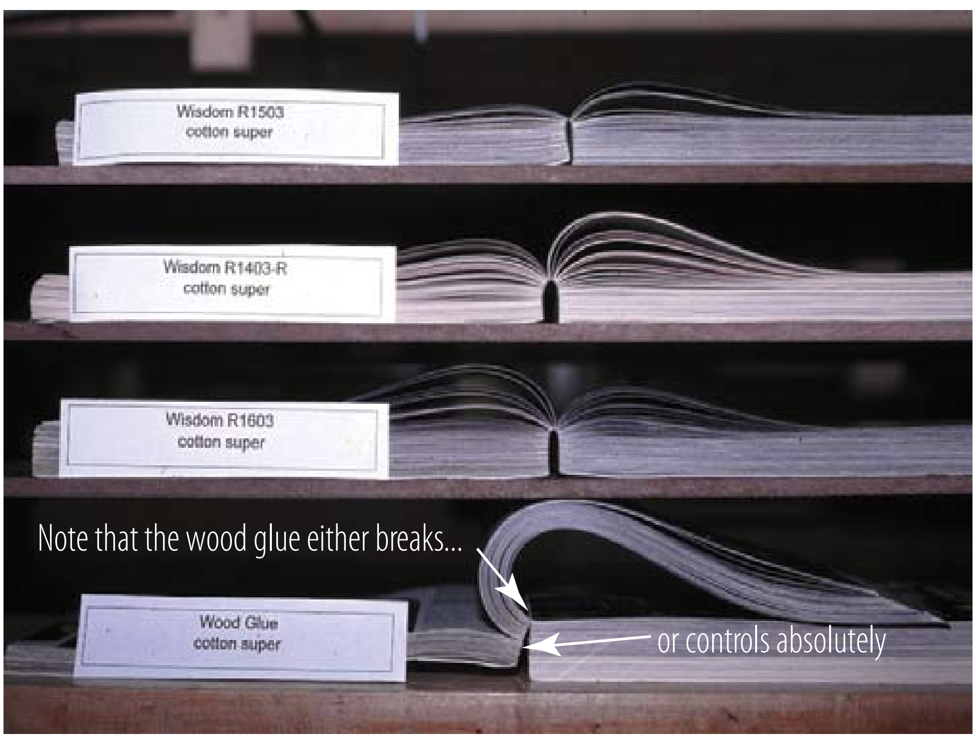
Once we move beyond paper and glue, the binder will frequently use any combination of materials such as cloth liners, paper liners, cords, tapes, synthetic materials like tyvek and even binder's board. What these materials do begins with an understanding of the pivot line.

The Built-up Spine and the Pivot Line

A book's spine is a three dimensional object comprised of not only the two obvious dimensions, the length and breadth of the spine, but most importantly the thickness. As soon as we add glue to the spine we add thickness, even if it is only a thin film. When we fan-glue we also must add to the accumulated thickness the depth of the glue between the pages. A super adds more thickness and any additional layers, cords or tapes continue the buildup. In order to understand how best to control the spine, we need to understand the basic physics of a three dimensional object when it bends or flexes. As a object bends the convex side expands and the concave side compresses. (See illustration on page 6)

The diagram on the next page assumes a homogeneous material that expands as well as it compresses. In this theoretical case the pivot line is represented by the red line in the middle, between the lines of maximum expansion and maximum compression. ***The pivot line is the line between the expansion and compression line where the original dimension of the object, before it was flexed, remains unchanged.*** Everything toward the convex side of the line expands and, conversely, everything to the concave side compresses.

Whereas everything can work in

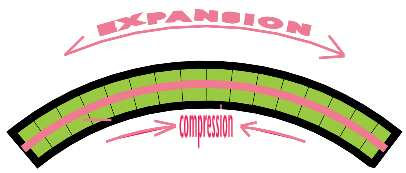


Four samples with the same type of paper, fan-glued with four different glues and lined with a single cloth liner.

A. Take any flat item

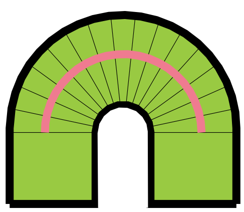
Top dimension = Bottom dimension

B. Bend it slightly (large radius)



Top dimension slightly excedes bottom dimension
Center line = Original dimension

C. Bend it some more (small radius)

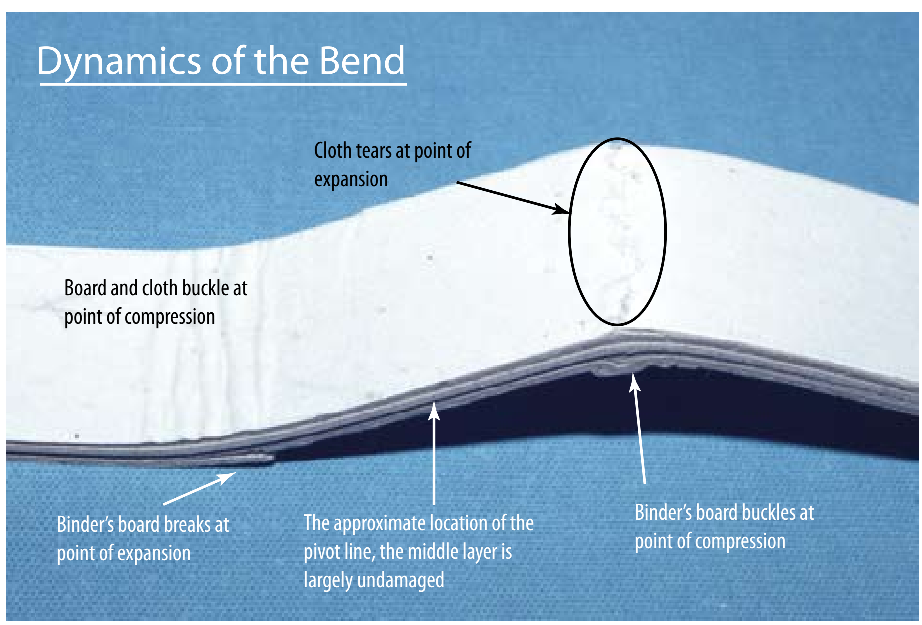


Top dimension greatly excedes bottom dimension
Center line = Original dimension

the theoretical world, the real world is quite different. The illustration to the right is a laminate of three pieces of thin binder's board with a cotton super on the top side. I did two hairpin bends on the sample in different directions to show the effects of bending a three dimensional object. The sample was purposely designed to exaggerate the results in a very visible way. Where the sample was bent such that the cloth super expanded, the cloth actually pulled apart. It did not require significant effort on my part to do this as the bending of the sample significantly leveraged my minimal effort at the point of expansion where the cloth broke. If you took a similar sample of cloth and tried to break it in the middle by evenly pulling at the two ends you would find this extremely difficult. A quick look at the reverse bend shows that the outer board broke. The forces of expansion are significant. The material expanding must be sufficiently elastic or giving to accommodate the required expansion or it will break.

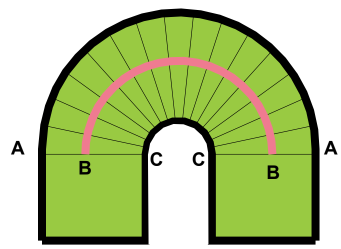
Before we leave our sample, we also need to look at the concave or compression side of the bends. In this case the compressive abilities of the board were exceeded and it buckled. The board actually delaminates and bulges out to accommodate the reduced dimension required by the compression. As is the tearing on the expansion side, this damage is not reversible and the area of the bend remains permanently weakened. We frequently see such damage in books with paper liners or in paperbound books where the natural flexing of the opening book has created lines of delamination at various points of opening. As the materials should be carefully considered for the expansion side of the bend so should our materials be considered for the compression side of the bend. Finally, note in the sample that the largely intact middle board forms the pivot line.

Once we understand the concept of the pivot line, we also need to understand that it is not necessarily in a fixed position relative to the opposing expanding and contracting areas. The following diagram (on page 7) shows three theoretical materials and how they might affect the pivot line. The first sample represents our original theoretical sample and also our bent board sample where the pivot line is located approximately in the middle (represented by the red line). The second sample is a theoretically inelastic



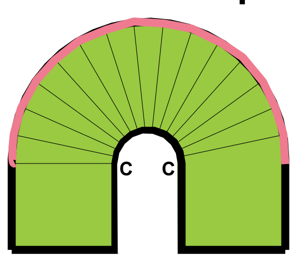
but compressible material. In this case there is no expansion because the material simply will not expand (yet has the strength to resist breaking) but it will compress. In this case the pivot line falls on the outermost side of the bend. With the third sample we have the reverse, where our material is very elastic, but incapable of compressing. In this case the pivot line falls to the very inside of the bend. While fully inelastic/compressible and fully elastic/incompressible materials are probably not actually available to the binder in a useful form, we can mix and match our materials to shift the pivot line favorably.

Elastic and Compressibile



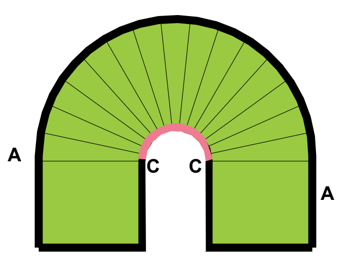
BB = Original dimension
Outer suface expands. Inner surfance compresses.

Inelastic and Compressibile



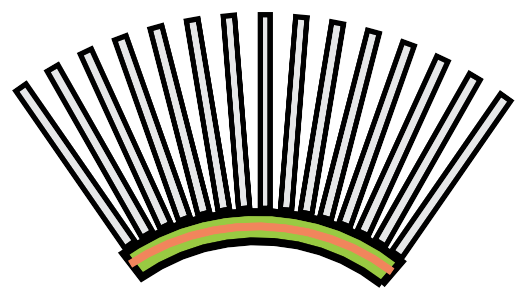
AA = Original dimension
Outer suface remains constant Inner surfance compresses.

Elastic and Incompressibile

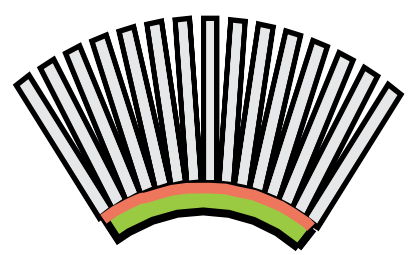


CC = Original dimension
Inner suface remains constant Outer surfance expands.

Why is the location of the pivot line important? The following diagram shows a spine structure with two possibilities. In the first the pivot line is in the middle or toward the compressive side of the spine structure and in the second the pivot line is at the point of leaf attachment. Given the first possibility the point of leaf attachment must accommodate a much greater level of expansion than the second possibility where the pivot line and the point of leaf attachment coincide. Ideally, as bookbinders, we want to achieve the second possibility which greatly reduces stress at the point of leaf attachment. This is especially true with fan-glued books but also true with sewn books where undue stress at the point of opening can cause the signatures to separate (see illustration on page 8).



A. Spine controlled from center
or outer edge



B. Spine controlled from inner edge

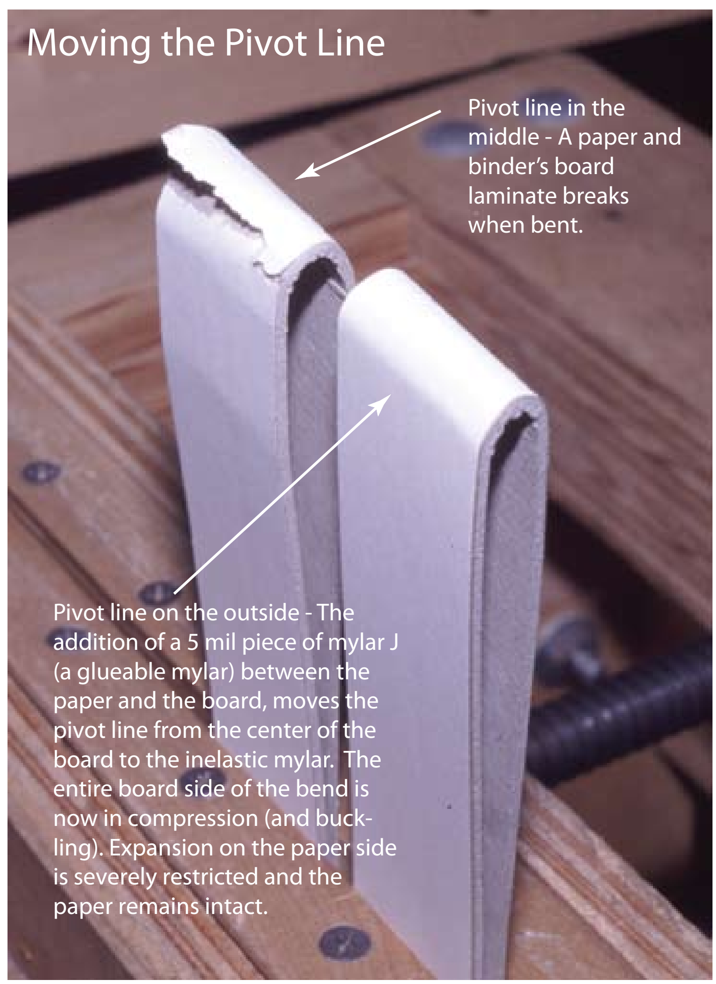
We vary the location of the pivot line in a book's spine through the materials we use. The illustration (Moving the Pivot Line - page 8) shows two almost similar structures performing quite differently. I laminated two pieces of binder's board; one with a piece of paper and a second with a piece of Mylar J between the paper and the board. When the first sample (without the mylar) was bent the paper broke. The

Sewing and pivot lines - the two samples above show the effects of sewing on the pivot line. The sample sewn with a chain stitch has a pivot line relatively close to the line of stitching. The sample sewn on cords (actually, clothesline) has a pivot line well removed from the stitching causing a significant spread at the line of stitching when the book is opened flat. This textblock will require signifcant spine control to prevent if from opening flat and pulling the signatures apart

pivot line in this sample is approximately in the middle of the board. Expansion begins in the middle of the board and moves out. The expansion at the apex of the bend was more than the paper could handle, and it broke. The addition of the mylar radically changes the pivot line. The mylar is the strongest and most inelastic material in the laminate. Because of this it becomes the pivot line even though the board comprises about 90% of the thickness of the laminated piece. When bent the board goes entirely into compression limiting the expansion on the paper side of the mylar to a now tolerable level.

Once we begin to build up the spine by thickening the glue or adding various liners, cords or other structural variations it is important to understand where we want our spine to give and where we don't. Materials on the convex side should be elastic or giving (as uncoated papers do by splitting). The elasticity or amount of give depends on the movement required. The smaller the radius of the opening arc the greater the elasticity and give required. Materials on the concave side should be compressive. If we are using spine structure alone to control the spine, the more material we add to the concave side the more controlled our spine will be. Ideally the pivot line should be as close to the glueline or point of page attachment as possible. With books having a large opening radius, placing the pivot line is less critical, as the difference between the line of maximum expansion and maximum compression is relatively small. However the smaller the radius the greater the difference in these two values and the more critical it becomes that the pivot line is as close as possible to the point of page attachment.

Without encroaching in the textblock, the only way to keep the glueline from spreading completely is to immobilize the spine completely. This gives us the most strength, but frequently the resulting book is hardly useable. However, to some degree we can limit the stretch at the glueline



by carefully selecting the materials and methods we use to control the spine. Though perfection is hard to achieve the best compromise will be achieved by understanding and designing around the concept of the pivot line.

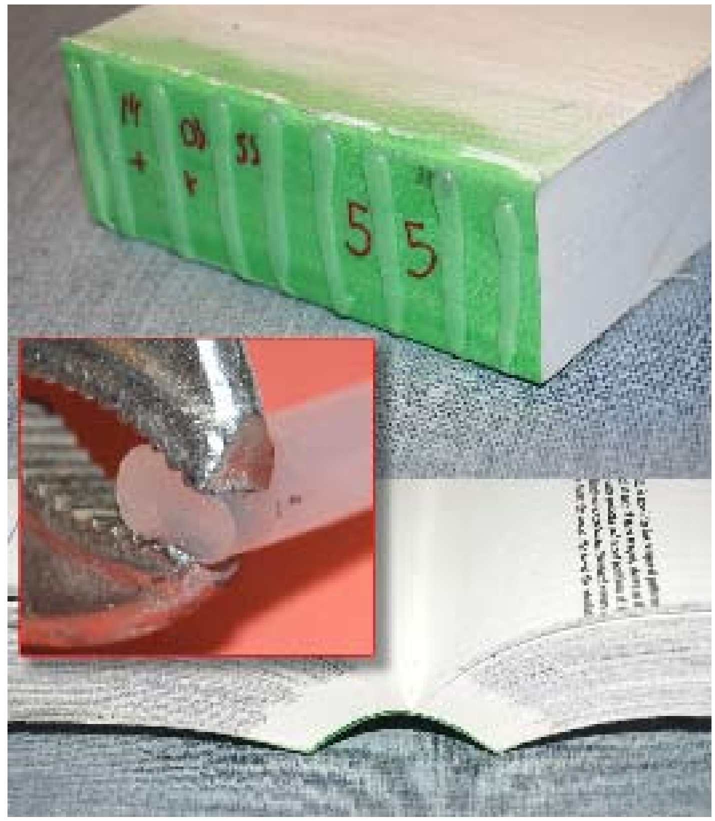
Controlling the spine - glue

The amount of control required is a compromise between what the paper requires and the effect the binder wants to achieve. Without addressing the issue of ideal control I would like to isolate various methods by which we can control the spine beginning with the glue.

As mentioned previously, all things being equal a stiff glue will control the spine more than a elastic glue. All things being equal a thick layer of glue will control more than a thin layer of glue. Cold emulsion PVA glues are seldom built into controlling thicknesses. On the other hand, hotmelt glues can be used in varying thicknesses to add control.

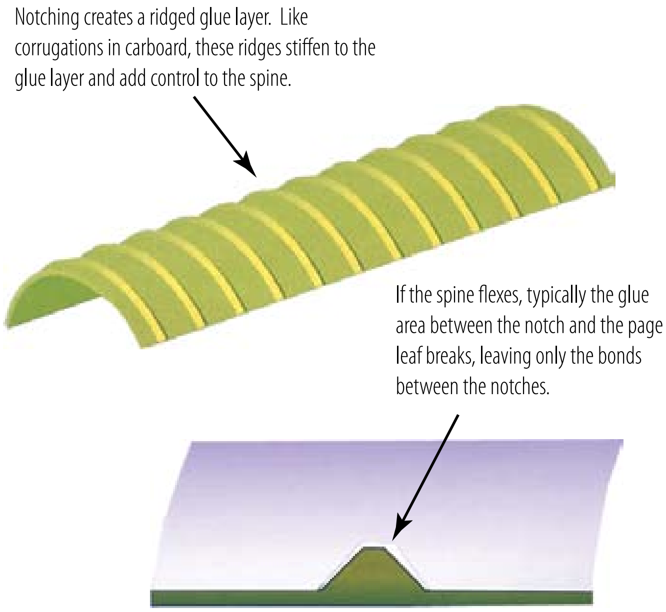
Hotmelt glues, however, come with their own set of problems. Because they set quickly they are generally unsuitable for fan-gluing and are used primarily for edge gluing. With hotmelts we cannot get the extra strength at the point of leaf attachment that we can get with fan-gluing using a PVA adhesive. Secondly, though hotmelts allow us to control the spine by simply thickening the application, when used as the primary means of page attachment they do not allow us to easily control the pivot line. The thicker the hotmelt, the farther the pivot line moves from the point of page attachment. Hotmelt adhesives can be suitable as a method of page attachment, but only where the the spine is fixed or highly controlled. Because the pivot line is often too far from the point of leaf attachment, the flat opening of a hotmelt binding will usually split the book. The split may not be cataclysmic, but it will expand the glueline beyond its elastic limit and, at the very least, leave a gap in the text where the opening was forced.

As there is a variety of PVA adhesives so also there is a wide variety of hotmelts. Of these my knowledge is sparse. I have done some tests using a simple glue gun with stick glue to lay beads across spine of textblock. This adds control but at the cost of raised cords (see illustration). Ideally a flat coat of even thickness would be better. Furthermore, the hotmelt I used adhered poorly and popped off after some use. The poor adhesion may be a function of either the way it was applied (laid on with no pressure working it in) or the glue itself. But my very basic experiments indicate that though hotmelts may be less than ideal for leaf attachment, there are probably hotmelts that would make an excellent choice for controlling layers on the compressive side of the pivot line.



Top: Sample textblock with beads of hotmelt glue added using a standard glue gun. Bottom: The same sample opened. Inset: A pair of pliers show the compressibility of a standard stick of hotmelt glue. When released the glue will slowly return to its original shape.

Though PVA adhesives do not build easily, the effective thickness can be increased through notching. ***Notching*** is a method whereby small, shallow grooves or "notches" are cut into the spine perpendicular to the length of the spine. In a larger commercial operation the notches are usually milled with a machine and are often vee shaped. In a smaller hand-binding operation the notches are often cut with a fine tooth saw and are rectangular. Notches can be cut at varying frequencies along the length of the spine. Whereas the extra strength of a notched binding is frequently attributed to the extra length notching adds to the glueline, I believe the added strength comes from stiffening of the spine. Notching effectively alters the structure of the spine



Notching

as does sawing the spine and gluing in strings. If you took a piece of paper that was 15" long (we'll say it is 2" wide) and added a series of little accordian folds across the width about a 1/16th inch deep, at sufficiently close intervals such that the length of your accordianed paper was now 10" long you will have approximated the glue line of a notched binding with a 10" spine. This "glueline" is 15" (the length of our unfolded paper) though the end to end length of the "spine" is now 10".

Think about the accordianed folded paper in your hand. At 15" length it flexed easily across the width. With the accordian folds the paper has stiffened across its width. We have corrugated our piece of paper and added rigidity perpendicular to the length of the paper. We experience this type of structural strength everytime we use corrugated cardboard. Notching effectively corrugates the spine of the book, adding rigidity to the spine. The concentration of glue in the notches essentially creates many small cords and further enhances this effect. The advantage of notching over actual cords is that the cords remain slightly elastic (assuming some elasticity in the glue), the depth of the cords can be less than actual string cords, and it is easy to add them at frequent intervals.

The added length of the glueline probably has little to do with the increased strength notching seems to add to a binding. A very close, magnified inspection of the inside gutter of a notched binding frequently shows that as the book is used, the cord of glue in the notched area works itself free of the paper to which it is supposed to be attached. This makes sense since these PVA cords represent a salient beyond the remainder of the glueline which sets slightly back. However, this brings us back to tests of notched bindings that do show improved strength. So, what does notching do to add strength if it is not the length of the glue line? Just as corrugated paper adds rigidity to cardboard by adding thickness, so I would say it is the added rigidity of the notched structure that contributes to the durability of the page attachment. In addition to adding control to the spine, notching positively affects the placement of the pivot line. Since the overall thickness of the notched spine encroaches into the textblock, the pivot line probably moves closer to the point of leaf attachment.

Controlling the Spine - Liners and Cords

With a fan-glued binding, notched or otherwise, I can think of no case where we would not add a cloth liner. The cloth liner serves two and possibly three functions. First it integrates with our PVA and reinforces the spine. Without the cloth liner the strength of the textblock is the strength of the glue between two sections. Once the cloth liner is added, the strength of the textblock becomes the strength of the cloth. Second, the cloth liner provides the structural connection to the boards or cover of the textblock. And third, the cloth liner, particularly if it is strong and inelastic, establishes the limit of the pivot line. If the cloth has sufficient tensile strength such that it will notstretch with the opening the textblock, and the glue on the leaf attachment side is elastic, the pivot line generally will not move beyond the liner (though the combination of glue, paper and liner may actually keep the pivot line slightly inside the liner).

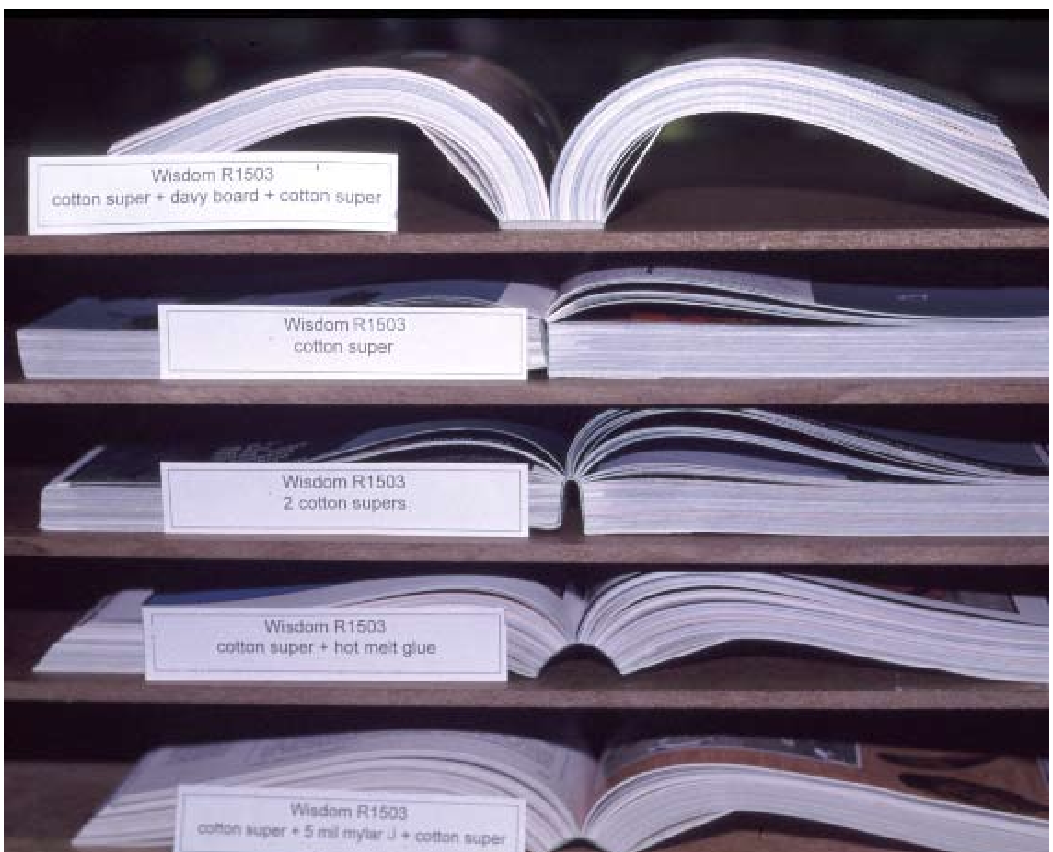
In addition to the structural strength of the cloth liner, we must consider the thickness of the liner. As with the glue or anything else we add to the spine, the thicker it is the more control it exerts and the more it affects the placement of the pivot line. Ideally a very strong and very thin liner is the most effective. If the book is designed to open flat (a small radius opening) it is particularly important that the liner be as thin as possible and that nothing further be added after the cloth liner.

Should our book require a larger radius opening (as would be the case with many coated papers) we can add control by thickening the spine. Ideally every thing added after the cloth liner should be compressible in nature. This is easier said than done. Traditionally, paper is often used as a liner. Paper stiffens the spine but is not actually compressible. An examination of most any used book that has a paper liner will show that the paper bunches and delaminates where it compresses. These delaminations become memory points to which the book will easily open and will tend to be the points most prone to failure. Once we begin thickening the spine it is important that our method of control remain consistent over time. As paper liners delaminate over repeated uses they become an ineffective means of control.

If not paper then what are the alternatives (assuming a perfectly compressible, adequately adhesible and infinitely layerable hotmelt is not in your toolbox)? For papers, such as thin coated papers that drape well, but still require slightly more control than a single cloth, I would simply double the cloth liner being sure to glue thoroughly both under the second liner as well as on top of it to ensure that the PVA permeated both liners to form a single thickened layer. The cloth combines with the PVA to build a compressible thickness. Achieving this requires cloth liners that are sufficiently porous to allow the wet adhesive to bleed through.

I also experimented with a 5 mil Mylar J (a glueable mylar whose competitive equivalent is Mellinex 454). Though Mylar is not typically found in bookbindings it has some wonderful properties that I find useful. It has the ability to add a durable, flexible stiffness. Once paper folds or creases it delaminates at the fold and will not return to its former stiffness. Unlike paper and board products, mylar resists folding and creasing. Because of this I used it to build endsheets for the quarter-joint binding (see article on "Flexible Strength"). I thought it might also be put to work controlling the spine. I layered a strip of mylar J between two cloth liners. This added almost as much control as beads of hotmelt, but with a much lower profile (see illustration below).

In addition to thickening the spine outward, we can thicken the spine inward with encroachments into the textblock. As discussed earlier, notching is one means of doing this. We can do this more aggressively by making the notches large enough to accommodate strings or cords. These cords can be of various thicknesses and are glued into the notches. Because cords tend to be inelastic, they add significant control to the spine and can easily immobilize the spine. The thicker, deeper and more frequent the cords the more they limit the motion of the spine. Inserting



The effects of different linings on spine control - The samples above are all glued with the same PVA but lined differently.

cords into the textblock affects the opening of the textblock in two possible ways. Should the cords remain fully adhered to the pages at their point of foremost incursion, the stress of opening the textblock is absorbed fully at those points rather than distributing along the length of the glueline. The spine on such a book will tend to be unyielding, much like a sidesewn book.

Should the cords break free, as the notched gluelines tend to in a notched binding, yet remain part of the spine structure (as in a notched binding) the stress of opening will now be distributed along the entire glueline. However, the inelasticity of the cords effectively moves the pivot line into the textblock inside the point of leaf attachment. Once the pivot line moves into the textblock, this effecively puts the glueline/point of leaf attachment under compression when the book is opened. This would probably be ideal except for the fact that this area is not very compressible. If a bent structure is incapable of compressing on its concave side and incapable of stretching on it convex side it will either not bend at all or, once sufficient force is applied, will break. Generally, the result of cords set into the spine is a spine that will move very little.

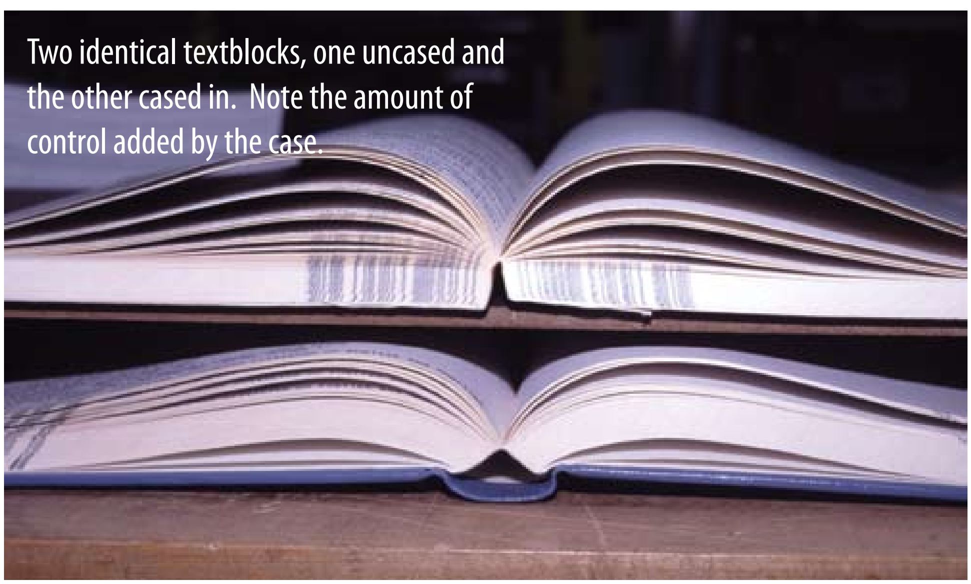
If our purpose is to immobilize the spine, set-in cords will do the job, but so will hot melt adesives as well as the addition of other stiff materials to the spine. The disadvantage of using cords is that they may be encroaching on very limited margins and there may be aesthetic objections to their appearance in the open book. The advantage is that the force to break such a binding is equal to force required to break the cords which is quite significant. I would not discount cords completely, but I would suggest that if they are used at all, very thin cords in shallow groves are most likely to give us the control we actually need.

Once we begin to control the spine by adding layers it is important to make sure control is sufficient to prevent the textblock from opening flat. As the spine becomes thicker the potential for self-inflicted damage increases. The thicker the spine the greater the spread at the point of leaf attachment. A book with a spine layered for control will often split when forced into a flat opening. Though the split may not actually separate the book in two, it may cause leaf detachment at the point of the split. At the very least it will create a "memory" spot to which to book will tend to open. However, if we are casing in our book with a hardcover, there are other ways to control the spine.

Controlling the Spine with the Case

Generally a book is cased in or covered without any thought to the fact that the case might add control to the motion of the spine. Such control is easily seen as we move through the process of binding a book. Open the book while it is still an uncovered textblock and note the degree to which it opens. Open it again when the binding is complete and again note the degree to which it opens. In most cases our book will not open with the same freedom it opened with as a plain textblock (see illustration). The difference between the two is a measure of how much control the case adds to the the book's opening. Generally, this added control is incidental to the casing-in and not part of our design process at all. But by understanding what is taking place we can integrate this control into our design process.

On any book whose spine flexes on opening, the two shoulders of the spine tend to move toward each other. The movement of these shoulders is a measure of the amount of control in the spine. As discussed in the previous section



Two identical textblocks, one uncased and the other cased in. Note the amount of control added by the case.

Both of these books have unyieding case spines and uncontrolled textblocks. In the top sample the case itself failed. In the bottom sample the hinge joint failed. In both books the potential energy of the open book exceeded the strength of the binding.

we can control this movement with various combinations of glue, liners and cords. The book's cover or case, however, can also control this spread. With proper design we can actually fine tune the case design to achieve most any opening radius to provide the needed control or to support the control already in the textblock spine.

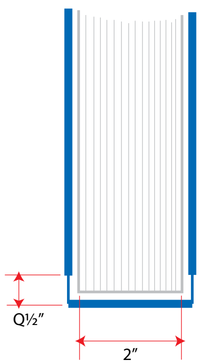
When a book opens, in order for the spine to arc, the case must give somewhere. In a normal hollowback book the case spine tends to flex. The amount of the opening arc is limited by the amount of flex in the case spine. The stiffer the case spine the more it will restrict a book's opening. If the case spine is inflexible the textblock cannot arc. If the forces of opening the book exceed the strength of the materials resisting the opening, the book will fail. In a traditional book with a hollowback case the stress of opening falls on the leading edge of the hinge joints. Frequently these joints will separate giving the book some of the flexibility it needs to open. If the case is unyielding and the textblock is uncontrolled failure is a natural consequence (see illustration to left).

With a standard case design we can control the case somewhat by our choice of materials. The thickness and flexibility of our book cloth can be mixed with various spine inlays to create various amounts of give. However, no matter how we assemble the case, the inherent weakness of the design remains. The ultimate point of stress remains at the leading edge of the hinge joint. This stress can be alleviated by putting most of our control into textblock itself. But this is not always possible or desirable. Building up the spine too much has its own problems. Ideally case and spine structure should work together.

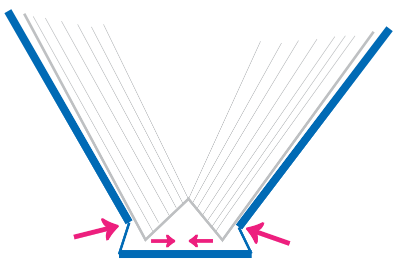
I found the quarter-joint case uniquely suited to the job of spine control. Almost 15 years ago I published an article called "Flexible Strength" that looked at the quarter-joint binding and introduced an endsheet construction that made it workable. The purpose of working with the quarter-joint case was not to control the spine but, to actually take the spine out of the control equation and to let a book open freely with no resistance from the case. This was accomplished by not adhering the joint areas of the case to the textblock and making them wide enough to provide the give needed to allow the textblock to open fully. The "quarter" in quarter-joint refers to hinge joints that are one quarter of the thickness of the textblock. Assume a sample book that is 2" thick . Unopened the corners of the spine are 2" apart. If we open such a textblock right to its middle such that it hinges at the point of opening, and allow it to open flat, the edges of the textblock are now side by side with virtually no space between them. There had to be a total of 2" of movement for this to happen. In this particular case, each edge of the textblock moved 1" toward the other side. By creating a joint area one quarter the thickness of the book that is unattached and free to move, the case spine can move out 1/2" (relative to the textblock) and the outer board can move in 1/2". (relative to the case spine) for a combined movement of 1". Since the movement is the same on both sides there is total movement of 2" and the book opens freely unhindered by the case (see illustration on page 14).

So, what does this have to do with spine control? Joint size in a quarterjoint case determines movement and how much a book can open without being hindered by the case. Conversely, a quarterjoint case, because of the stiff binder's board which lines the spine, cannot allow any more motion than that built into the case. A joint sized less than one

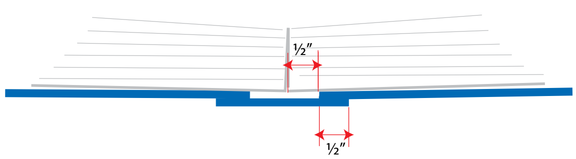
Quarter-joint Math



Start with a book 2" thick with 1/2" joints (1/4 the thickness of the book)



As it opens the two corners of the textblock move toward each. The joint areas move freely away from the textblock as the boards move with the textblock.



The distance between the corners of the spine is now zero. The corner of the spine has moved in ½" relative to the edge of the case spine. The case spine has moved out ½" relative to the textblock spine for a total of 1" of movement one side and 2" of movement for both sides.

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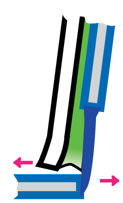
quarter the thickness of the textblock limits the opening of the finished book. Getting back to our 2" thick textblock, a 1/2" joint allows 2" of motion or full opening. However, a 1/4" joint would allow only 1" of motion and would prevent the edges of the textblock from coming closer that 1" together. Assuming there is no control built into the textblock of the spine, the case assumes full control by holding the textblock in a state of tension. By adjusting the width of the joints from one quarter the thickness of the spine on down to the smallest manageable joint width our materials will allow, we can almost dial in the amount of control we want in the spine. Instead of quarter-joint case being defined by the thickness of our textblock, it is now defined by one quarter of the amount of motion we want in the spine.

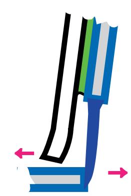
The advantage of the quarter-joint construction is twofold. First, and as already mentioned, is the ability to fine tune the amount of control by adjusting the width of the hinge joint. The second advantage is that the quarter joint case plays to the strength of our materials and adhesives. Whereas the stress on a traditional case is a peeling force at the leading edge of the hinge joint, the stress on a quarterjoint case is a pulling force on the edge where hinge meets boards (see diagram below). All things being equal a pulling force distributes stress whereas a peeling force concentrates stress. A quarterjoint design plays to a strength whereas a traditional design plays to a weakness. However, this design does require boards that are adequately stiff and covering and lining materials with good tensile strength.

The effect of case design on the strength of leaf attachment can be significant. I tested two sample bindings com-

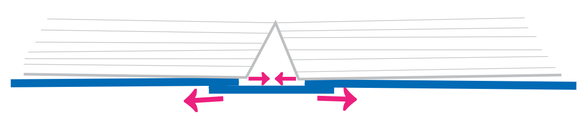
Quarter-Joint Hinge - From peel to pull



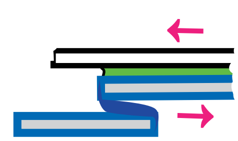
In a traditional tight joint stress concentrates as a peeling stress at the foredge of the glue joint. This relationship is maintained through the full opening of the book with the case pulling out and the corner of the textblock pulling in.

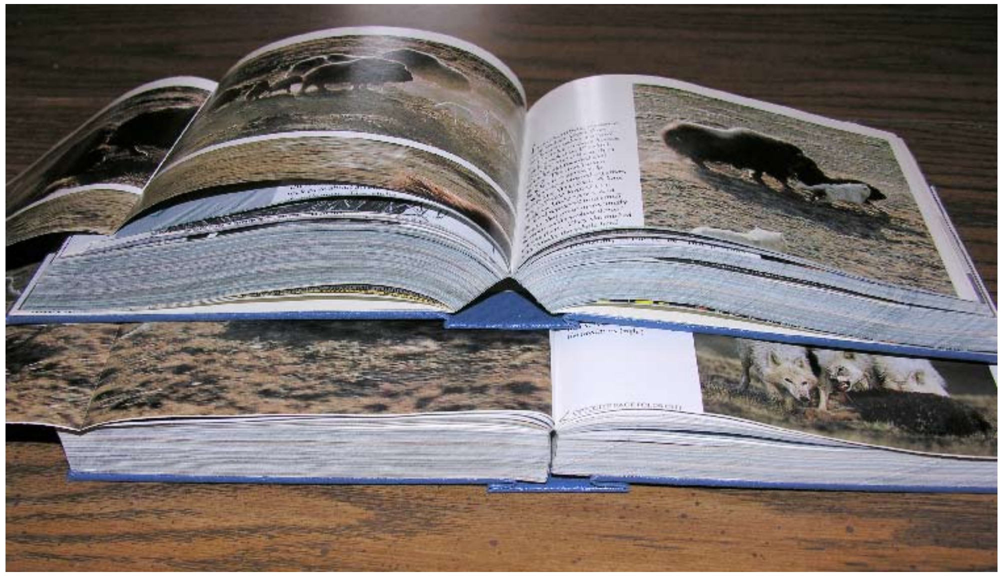


The loose hinge in quarter joint case gives into the movement rather than resist it



With the book fully open stress in a quarter-joint cover runs parallel to the glue line (endsheets to cover) playing to the strong pull strength of the glueline. This contrasts with traditional case bindings where the stress of the opened book tends to exert a peeling force on the glueline.





The only variation in the quarter-joint books above is in the joint size of the case. The page pull test results for the top book were double those of the bottom book.

prised of a stack of National Geographic magazines. To ensure the compatibility of the samples I made one book from the top half of the magazine and the other from the bottom half for a finished textblock size about 4" high by 5 1/2" wide x 1 3/4" thick. The two samples were matched page for page. The pages were fan-glued with Wisdom R1603 glue, a glue that is flexible but of relatively low elasticity (a stiffer, more cohesive glue). Each sample was cased in with a quarter-joint case, the only variation being the size of the hinge joint. The spine of the first sample moved freely (see illustration). Pull strength averaged 13.6 lbs. The spine of the second sample was controlled such that it opened in a gentle arc. Its average pull strength was 28 lbs. Controlling the spine doubled the pull strength. The only difference between the two samples was in the case design. The textblocks were identical (see illustration above).

This brings us back to the beginning of our article and our microphoto of the coated paper binding. Increasing spine control whether by altering the spine structure or through case design increases durability by protecting the bonds between pages (as measured by page pull testing) in bindings *where the adhesive bond between fan-glued pages is problematic*. Similar tests to books with uncoated papers showed no significant difference in page pull tests.

The Built-up Spine or Case design

When do we control by building up the spine and when do we control with case design? My answer is that we do both. Controlling the spine purely with case design can work with the right materials and design, but with a large book there can be quite a bit of tension in the spine. Putting some control into the spine itself reduces this tension.

A quarter-joint case can also be used to limit the motion of the spine such that it does not exceed the control built into the spine itself. For example, when binding books with coated paper, I would often build up the spine to the appropropriate level of control and then match the quarter-joint case to the natural movement of the textblock. The case provides a virtual lock on the motion of the spine that would prevent a user from forcing the book open to the point of damage, as someone might be inclined to do on a photocopy machine.

On the other hand, assume a book calls for a traditional case design. Almost all standard case designs tend to unintentionally add control to a book. Having no control in the textblock and non-intended, incidental control in this case frequently leads to delamination of the hinge areas if the book recieves any significant use. Adding control to the spine can alleviate this. Where the case spine is quite stiff (fake raised bands on a hollow leather spine come into mind), putting adequate control into the spine takes the stress off of the case and can prevent the type of case failure pictured on page 13.

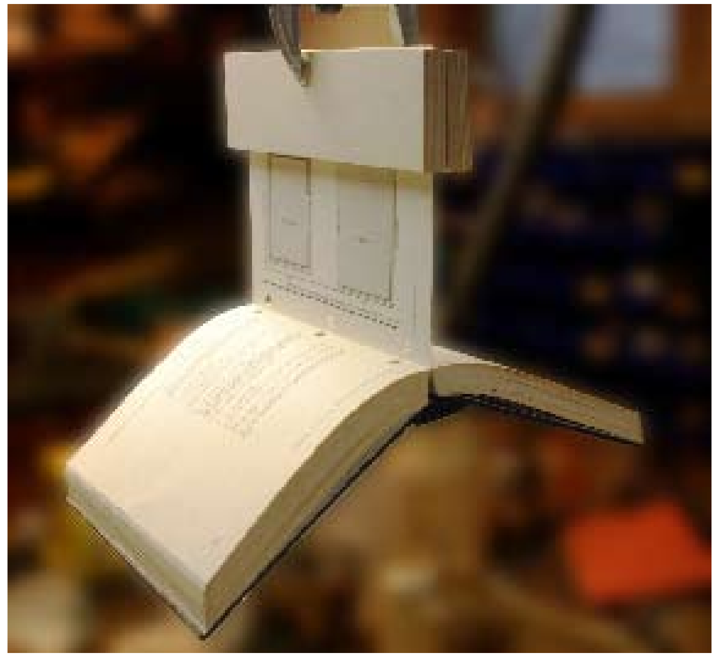
To Control or Not to Control...

The reasons for controlling the spine vary from durability to useability to aesthetics. Whereas a flat opening quarter-joint book may rank high in useability, it may not be the look we want to achieve even if we can do it durably. We should also be aware that the options to control include both less control (toward a flat-opening book) and more control (toward a gentle arced opening or even a fixed spine). Some materials may suggest either.

For instance, thick, stiff papers may offer several options depending on the perceived behavior of the end user. As paper gets thicker, a fan-glued binding poses greater challenges. With thicker papers, glue tends to encroach more deeply between the pages than it will with thinner papers. This combined with the stiffness of the papers usually requires significant control to counteract the stiffness and to protect the bond between the pages. However, if the paper is thick enough (like a 10 mil cardstock) we probably have enough surface on the edge that we don't need glue between the pages. Such a book can be clamped tight, edge-glued with an elastic glue, lined with a single cloth liner and put in a quarter-joint case. The result will be a very flat opening book that will be durable if properly handled. Here is where the perceived behavior of the end user comes in. The pages in such a book are easily peelable such that they can be peeled out from top to bottom (think of a gummed pad) if the user so desires. However, if the user is not inclined to peel the pages out they will remain intact. However, if your perceived user is the general public (such as library patrons) you may not want to offer them such an easy opportunity to lift pages from the book. In this case, you would fan-glue and add maximum control. The end result would be a very stiff binding, but one that would be significantly harder to vandalize.

Though I have focused on fan-glued bindings, this is not to imply than fan-gluing is always the solution. Frequently binders do not have the option to choose the paper and format of the book they bind. However, if we could choose, I would recommend that books with stiff heavy, coated papers (such as is found in many artbooks) be printed in signatures, sewn without tapes or cords and cased in a quarter-joint cover. Sewing would alleviate the problems of protecting the glue joint between the pages (which are unnecessary in a sewn binding) and the need to control the spine. Avoiding cords or tapes will keep the pivot line close to the point of leaf attachment so the book could open freely without undue expansion where the signatures meet. The quarter-joint case will allow the textblock to move freely and open flat.

Though sewn bindings are sometimes the best design solution, this is qualified with the understanding that the structural dynamics of the spine apply to sewn bindings also. Understanding the pivot line in relation to different sewing structures can lead to designs that work as intended or, at least, lead to a better comprehension of those that fail. As sewing structures become more "supported" with tapes or cords, the pivot line moves away from the point of leaf attachment and the need to control the spine becomes greater, lest the sewing itself becomes a leveraged force of destruction.



An edge glued. stiff -paper (.007") quarterjoint binding. The pages in this binding can be peeled out, but book is quite durable if not abused.

Conclusion

How a spine is controlled affects how a book works, how long it lasts and how it will ultimately fail. The simple attachment of a book's pages at the glueline cannot be understood simply as a relationship between glue and page but as a relationship between the page and the entire book structure. Traditionally, spine control is seldom considered in the design process but is the incidental result of the methods and machinery at our disposal. The techniques I have proposed in this article are few, but hopefully the ideas are enough to encourage a greater comprehension of the dynamics of the working book as a basis for experimentation and better book design.

Postscript

After I concluded this article, I was rummaging through my samples in search of several I wanted to re-photogragh and came across the mylar test book above. I originally put this together to show that with sufficient control you can glue most anything. The mylar in this sample is not Mylar J (the glueable mylar) but the more commonly found Mylar D (which is barely glueable). Mylar D represents a worst case scenario. It has a high drape factor and any glue apllied to it can be peeled off when dry. However, this sample works (though it does require at least one hand to keep it open). I fan-glued the Mylar textblock with an elastic glue (Wisdom R1503), lined it three times with a cotton super using a stiffer glue (Wisdom R1603) to consolidate the supers, and finally added a layer of hotmelt to thicken the spine.