Some Introductory Notes Concerning Jacquard Technology
by Garth Fletcher for submission to the Complex Weavers Jacquard Study Group

Introduction and disclaimer: As the author of the JacqCAD MASTER® CAD program used for Jacquard textile design I program computers rather than looms, so my textile knowledge is second hand at best. Nonetheless, during my twenty years of work with textile software I have been privileged to work with a number of professional Jacquard designers and to encounter a goodly range of industrial Jacquard looms. If you take my comments with suitable "grains of salt", and perhaps some amused tolerance, I hope you might also find therein some nuggets of truth.

As in any field of specialized knowledge, an extensive jargon has been evolved. Textile jargon, developed in many places over many centuries, is especially rich and variable. The same or similar words often have different meanings in different branches (hand weavers versus mills), in different countries (US versus England), and sometimes even between mills in the same State. Where possible I have tried to describe the mechanism rather than to simply name it.

Overview – how does a Jacquard loom differ from other looms:

The term "Jacquard loom" is a bit of a misnomer. The Jacquard mechanism is just one of the components of a loom, not the entire loom itself; let me clarify.

Any textile loom includes the following essential mechanisms (Figure 1)

1) warp supply (**Y** at right)

2) weaving stage, containing mechanisms for:

   2a) shed formation **(H&M)**

   2b) weft insertion

   2c) beating up (reed)

3) fabric take-up **(PR&CR)**

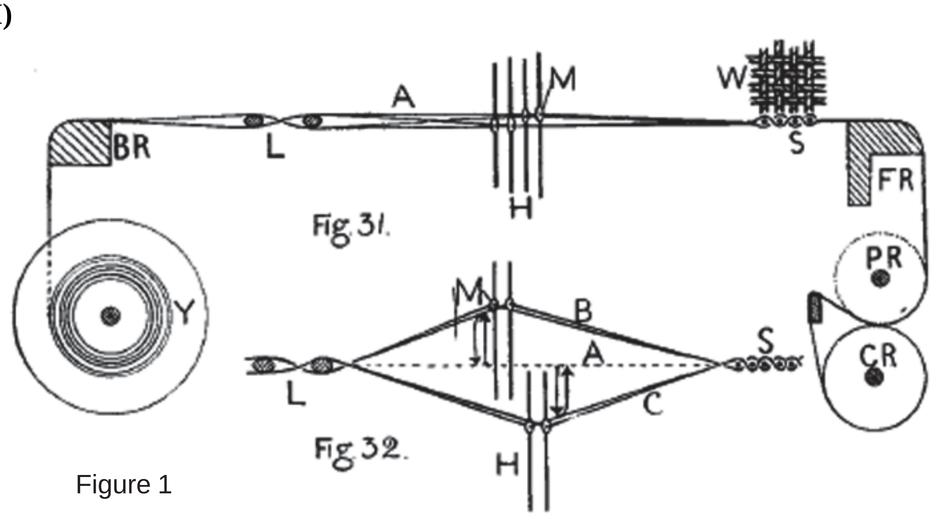

Figure 1

The shed formation mechanism simply divides the warp ends into two groups - one group being lifted while the other is held down - to form an open channel, called the ***shed***, between the two warp groups. Once the shed is formed, the weft is inserted through it and then the reed is brought forward to beat up (pack) the newly inserted weft to its desired position. The cycle continued with formation of the next shed...

The principal differences between so called plain, harness, drawboy, dobby, and Jacquard "looms" lie in the shed formation mechanism (2a below). A more accurate description would be a "loom with Jacquard shedding" rather than a "Jacquard loom".

Perhaps this seems an overly picky point, but what would you call a loom that combines a dobby mechanism for a border pattern with a Jacquard mechanism for the central figuring? Such mixed shedding mechanisms are not unusual.

Similarly, while there are enormous differences between a hand loom and a power loom, either can be fitted with a Jacquard shedding mechanism. Indeed the original Jacquard mechanisms were designed for hand looms.

Shed formation mechanisms:

Shed formation is the central technology of weaving. No other aspect of the loom has received as much attention, nor been elaborated into as many complex variations.

Each warp end passes through a single ***heddle***, consisting of a central eye for the warp and upper and lower eyes (see Figure 2) for attachment to the mechanism. The shedding mechanism does its work by raising or lowering the heddles, hence the warps.

In broad terms there are two techniques for acting on the heddles:

a) via thin *harness cords* which individually connect each heddle farther into the shedding mechanism, as in draw or Jacquard looms, or

b) via *heddle frames* which hold a large number of heddles to allow them to be moved as a group. These are similar to a picture frame with the upper and lower eyes of the heddles sliding along the upper and lower bars – see Figure 3.

Although the word "harness" would seem to best refer to the collection of harness cords, it is often also used to describe a heddle frame (as is the word *shaft*, probably from the shaft used to drive the frame up and down) – I did warn you.

The simplest possible shedding mechanism uses 2 heddle frames to divide the warp into 2 groups – for example the odd numbered warps (1,3,5,...), which pass through heddle eyes in Frame #1 but between the heddles in Frame #2, hence are not affected by its motion, and the even numbered warps (2,4,6,...) which pass through the heddle eyes of Frame #2. The loom lifts only Frame #1, inserts weft, then lifts only frame #2, inserts weft, and so on, to weave plain cloth, - the only kind that can be woven on this basic loom.

More flexible mechanisms divide the warp into more groups - occasionally using as many as 40 heddle frames (I even saw a reference to the use of 90 frames in an 1800's loom), but usually no more than 24. Any combination of harnesses can be lifted simultaneously. This provides a very large number of different sheds - with 8 harnesses there are 256 possible combinations (2 x 2 x 2 x 2 x 2 x 2 x 2 x 2), while 24 harnesses provide 16,777,216 combinations. If the harness combinations are lifted by hand (or foot), this sort of loom is often called a "harness loom".

Manually setting up combinations of two dozen frames would be impractically laborious so a simple form of "programming by tie-up" is used. The user connects cords between the frames and foot pedals (treadles) so that, for instance, pressing down treadle #1 would lift frames 1, 5, 7, and 22 while pressing down on treadle #2 might lift frames 3, 5, and 14, and so on. The shedding sequence is thereby changed into a series of presses on individual (or pairs of) treadles which, via the tie-up of the cords, create the desired frame combinations. This approach greatly simplifies the operation, but also reduces the total number of frame combinations which can be used in a design. This compromise is not necessary with mechanically operated frames, see below.

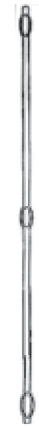
Figure 2

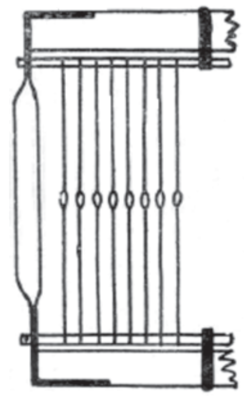
Figure 3

Simple mechanically operated looms use cams to directly operate the frames in a simple fixed sequence of combinations - for example to weave large amounts of plain satin fabrics. This sort of arrangement is often described as a "cam driven multi-shaft" loom.

When a longer or more complicated sequence is desired, a programmable mechanism is used to allow the sequence of frame lifts to be controlled by paper tapes, chains, peg boards (from which "peg plan"), or directly by computer. The result is a "**dobby**" mechanism. All frame combinations are usable without limitation - you simply insert or don't insert a peg for each harness (or punch or not punch a hole).

One common implementation uses punched tape (usually Mylar tape for strength) which has places (channels) for up to 40 punched holes per row, each hole corresponding to a lifted frame. Most industrial looms use 24 or fewer frames, and the unused channels in the tape are often used instead for other functions such as selecting the weft color. A very common arrangement is

channels 1..24	control frames 1..24,
channels 25..30	unused,
channel 31	controls the Regulator (inhibits fabric advance)
channels 32..40	select wefts 1..8

The sequence is punched, one row for each weft insertion, and then the two ends of the tape are glued to form a continuous loop – simply insert into the dobby mechanism, start up the loom, and watch your fabric weave. Newer dobby looms are completely electronic – just download the design via memory card, floppy disc, or network and go.

As discussed, the number of frames is usually limited to 24 or less. Each frame takes up some space and a stack of 24 frames gets to be cumbersomely deep (to keep the shed angle constant the frames towards the rear must be lifted higher than those at the front).

While there are a huge number of possible combinations, the design is still greatly limited by the fact that the warp can be divided into no more than 24 independent groups. Figures can be detailed, but only if they are very small (24 ends wide), or can be wider, but only if less detailed. This can be alleviated only slightly via fancy or mirroring threadings. Consider weaving a pattern which would simply divide the design along a diagonal line from the lower left corner to the upper right corner. With only 24 groups this diagonal must be a staircase taking 24 coarse steps. If we instead go for fine detail, then our diagonal can only cross 24 ends before it must repeat.

The drawloom or drawboy loom used a harness rather than heddle frame to provide the next level of control. Warp groups were created by tying together selected harness cords which could then be lifted manually as a group. This permitted many more groups, thus provided much more resolution in figuring, but became very difficult to operate as the number of groups soared. Attempts to solve this problem led naturally to the next step. That next step in shedding evolution was to provide for a much larger number of independently controlled warp groups - many hundreds to over ten thousand - this is the **Jacquard** shedding mechanism - an evolutionary step with revolutionary consequences.

From an evolutionary perspective we are simply increasing the number of frames from a couple dozen to thousands while at the same time reducing the number of warps assigned to each frame from many down to only one. Like a Dobby mechanism we may use paper tape or cards to control the warp lifts; however instead of having 40 possible holes (channels) for each weft insertion we will have hundreds or thousands.

Because there is only a single warp end assigned to each "frame" we don't actually need a physical frame to contain and lift the heddles. Instead we can simply run a thin cord from each hook in the Jacquard mechanism down to the corresponding heddle. This greatly reduces the amount of hardware around the warp - indeed each warp end simply goes through its own heddle and lies adjacent to only a few neighboring heddles, allowing greater heddle densities.

The revolutionary aspect is that all design limitations have been removed.

We can easily weave a completely smooth diagonal across the entire design - unlike the Dobby where we could either make only small smooth diagonals or very coarse stair-step large ones.

We no longer have to make choices about the assignment of warp ends to heddle frame (the "draw-in") nor do we have to rethread the warp - every warp end is its own group of one.

In short we can have great detail across the entire design without any trade-offs between detail and size, and we can weave radically differing designs without rethreading the warp between. Liberation!

A side trip into history:

T.W. Fox writing in 1894 deprecates Jacquard's 1804 design as little more than a simple adaptation of the earlier mechanisms of Falcon (1728) and Vaucanson (1746). Others tend to give Jacquard much more credit, though generally also mentioning Falcon, Vaucanson, and others as significant contributors. Leaving aside the attribution wars, it is historical fact that Jacquard's mechanism became the standard which is still in use today, albeit with many small improvements along the way.

The problem faced by the designers was how to amplify a small delicate motion – the sensing of the presence or absence of a small hole in a punched card – into a large and powerful motion – the lifting of a tensioned warp end to create a shed. The mechanism had to be compact, so that thousands could fit in a reasonable space, extremely reliable, fast, and economical. The solution of Jacquard *et al*, brilliant in its simplicity, is still in use today.

The power is provided by a strong geared mechanism which raises and lowers steel bars (*griffe*) to open and close the shed – the angled bars at the top of Figure 4. Long flexible double ended hooks are arranged to hang by their top hook from the narrow top edge ("knife edge") of the griffe, hence are lifted by it when it is raised. The lower end of these hooks connect to the heddles via harness cords, thus lifting the warp end when the heddle is raised.

When the griffe is in its lowest position, as shown in Figure 4, the bottoms of the hooks rest on a support so that their top hooks are raised slightly off of the griffe. At this point a slight sideways force is sufficient to deflect this upper hook away from the knife edge – just far enough that it is missed by the griffe on its next ascent, thereby

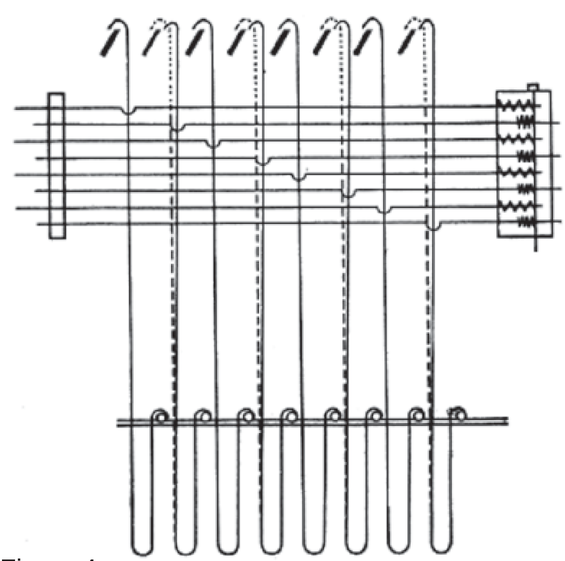

Figure 4

leaving the hook unraised. This provides the required amplifier – if the hook is pressed gently towards the griffe it will be lifted when the griffe goes up, if the hook is pressed gently away from the griffe it will be left behind when the griffe goes up.

Every hook is connected to a corresponding horizontal sensing pin. These pins are spring loaded (along right side in Fig. 4) to gently hold the hooks near the griffe and they protrude out into the card sensing area along the Figure's left edge. When a card is pressed into position the pins which pass through holes in the card will be left unchanged. However, those which meet unpunched areas in the card will be pushed back (towards the right), thus moving their hook away from the griffe.

The result is that a hole in the card results in the associated warp end being lifted while no hole corresponds to the warp end being left down. Figure 4 shows, reading top to bottom, an alternating cut / miss sequence corresponding to a tabby weave (Pins 2, 4, 6, and 8 being pressed towards the right by an unpunched card).

The amplification achieved is remarkable. The pressure applied by the sensing pins must be very low – the cards are made out of paper and must be read millions of times without wear. The hooks, however, must be able to provide a very considerable amount of force to quickly deflect the tensioned warp end. If we assume that, say, 1/2 lb of force might be needed at the hook, a Òquad widthÓ head (5376 hooks) could be called upon to provide 2,688 lbs of force – which is why you see Jacquard heads mounted on sturdy steel gantries!

The reliability is also extraordinary. Modern looms run as fast as 800 picks/minute, and they do so 24 hours a day. In a year's time this amounts to 800 x 60 x 24 x 365 = 420 MILLION cycles. Our hearts wear out in about 1/10 that number of cycles.

Though Vaucanson's 1746 design used punched paper, much like a player piano, this was found to be unreliable. Jacquard's design used individual paste-board cards (Figure 6), one per pick, laced together to form an endless chain (Figure 5). This was the standard technique used through most of the 19th century until Verdol reintroduced endless paper towards the end of that century.

Verdol's endless paper, which avoided the need for lacing and was much lighter and capable of higher densities and speeds, became the dominant media during the 20th century, though to my knowledge looms using laced "hard cards" were still in industrial use in the 1980s (and may still be weaving away today).

Although punched paper is still in wide use, the trend since the 1980s has been toward electronic control (first attempted by Bonelli around 1860, yes, eighteen sixty). This is achieved in effect by replacing the sensing pins with small electromagnets; the underlying principle of gently deflecting the hook to either catch or miss the rising griffe is still used to provide the necessary power.

The only exception of which I am aware is the recently introduced TC-1 by Digital Weaving Norway which uses small pneumatic cylinders to directly lift the hooks. This specialized shedding mechanism is designed to provide a very compact loom (the Jacquard head rises only inches above the warp), but at the cost of being quite limited as to speed and shed lifting force. Its primary application has been to small hand-looms used in studio weaving or for making test samples.

During the 19th century typical Jacquard sizes (the number of hooks) ranged between 100 to 1000 hooks. Verdol's endless paper model was originally produced as an 896 hook machine, later expanded to 1344 which largely became the standard Òsingle widthÓ head for the 20th century.

It was common practice to mount several heads on a single loom to provide greater resolution. Bradbury's 1912 "Jacquard Mechanism and Harness Mounting" begins with a picture of a street scene woven using 3600 hooks. Its detail is extraordinary, the wet street glistens! (see Figure 7 on following page)

The most common counts were 1344(1X), 2688(2X), 4032(3X), 5376(4X) and 6720(5X). When mechanical heads were in use, they were literally mounted in parallel above the loom with each head reading its own loop of cards (which could give rather "interesting" results when one of the loops got out of synch).

The 1344 hook Verdol card actually consisted of 3 groups of 448 hooks, separated by sprocket holes. Physically they are about 18.5" wide with 168 holes across the width (3 groups of 56) with 8 rows being punched per card, followed by a 9th unpunched row to separate the cards.

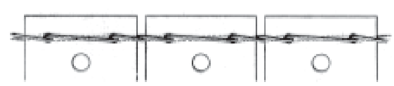
Figure 5

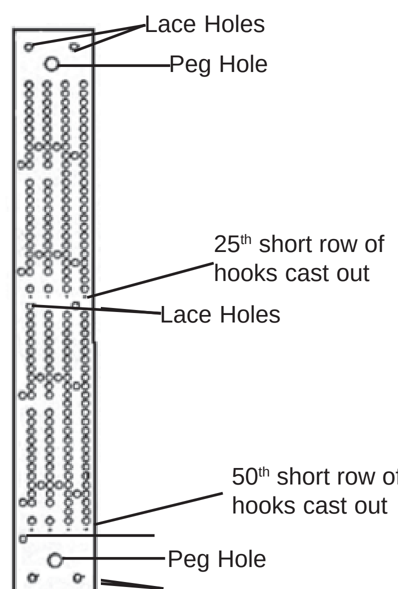

Figure 6

Figure 8 shows the left 1/3 of 2 such cards, reproduced at half scale; actual size of each card is 18.5" wide by 1.1" tall. The continuous paper is folded every 20 cards in a zigzag pattern, with "Pendaflex" style hangers glued on at every other fold so that the entire loop can hang on rails.

The physical mechanisms of the head were generally designed in "chunks" of 448, with the hooks often arranged at the comberboard as a group of hooks arrayed 32 wide X 14 deep (front to back).

Modern electronic heads don't use physical "cards" of course, instead they are controlled by data on a disk drive. Early models adhered to the same standard widths - multiples of 448 such as 3X (1344), 6X (2688), etc. Later models used multiples of 512 (a "nicer" number for electronics and computers) which provide widths such as 1536 (3X), 3072 (6X), etc. In these later models the hooks are usually arranged 16 or 32 deep (front to back). The largest head of which I am aware, Staubli's "Jumbo", is 12,288 hooks wide (24 X 512).

A Reproduction of a Woven Fabric.
The fabric contains 3600 threads in the repeat, and involves the use of an equal number of individual figuring hooks to produce it.

Figure 7

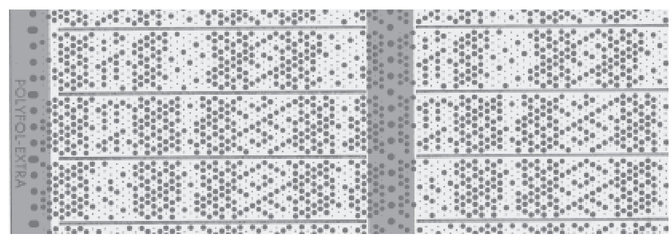

Figure 8

The harness and repeats

Up to now we have discussed the Jacquard as if each of its hooks lifts one and only one warp end. As discussed below the situation is somewhat more complicated.

For example, warp densities for upholstery fabric are commonly a bit under 200 threads/inch. A single head of 1344 hooks can thus only create a pattern that is 1344/200 = 6.7 inches wide. A quad head (5376 hooks) can create a pattern almost 27" wide. Indeed, the industry standards for upholstery are based on 6.75, 13.5, 27, and 54" repeat widths. At these warp densities even the 12,288 Jumbo head can only weave about a 60" wide repeat. At the same time, industrial looms weave at least 54" wide, and many are meant for 108" or wider.

In order to fill out the width of the loom, the pattern can be simply repeated across the width of the loom. Physically this is done via the "harness".

Consider the case of a 2688 hook "double" head controlling a 54" wide loom. The total warp count will be around 10,752 and will require 4 repeats of the 2688 wide pattern.

The Jacquard head is mounted high above the loom. Four cords are then run from each hook to the 4 heddles which control the 4 individual warp threads. For example, Hook #1 will be tied to cords which connect it to heddles #1, #2689, #5377, and #8065. Hook #2 will be tied to heddles #2, #2690, #5378, and #8066. And so on to Hook #2688 which will tie to heddles #2688, #5376, #8064, and #10752. Of course this means that each hook will now be lifting 4 warp ends, hence must be capable of considerable lifting force (does the 1/2 lb force per hook I used in my previous example begin to seem more reasonable?).

Special harnessings are often used – for example instead of simply repeating the pattern side by side, one could mirror (left/right reversal) the second (and fourth) repeats to create a symmetrical design which appears twice as wide.

Even more elaborate arrangements are used – for example, Figure 9 (next page) shows a harness for a dual-width Jacquard (two mechanisms in parallel) which does both mirroring, for the border design, plus a 3 fold regular repeat of the central figure. Entire books have been written on this topic.

It is important to keep these harness cords fairly straight - i.e., without sharp bends which would create a lot of friction and wear. This means in turn that the head itself must be 12 feet or more up in the air which results in an awkward and top heavy machine.

The harness is an expensive item. In our earlier example, a 4X repeat, it contained 10,752 cords connecting from 2688 hooks at the top end to 10,752 heddles at its bottom end. The cord lengths must be exactly calibrated so that the heddles all line up... Harnesses are generally

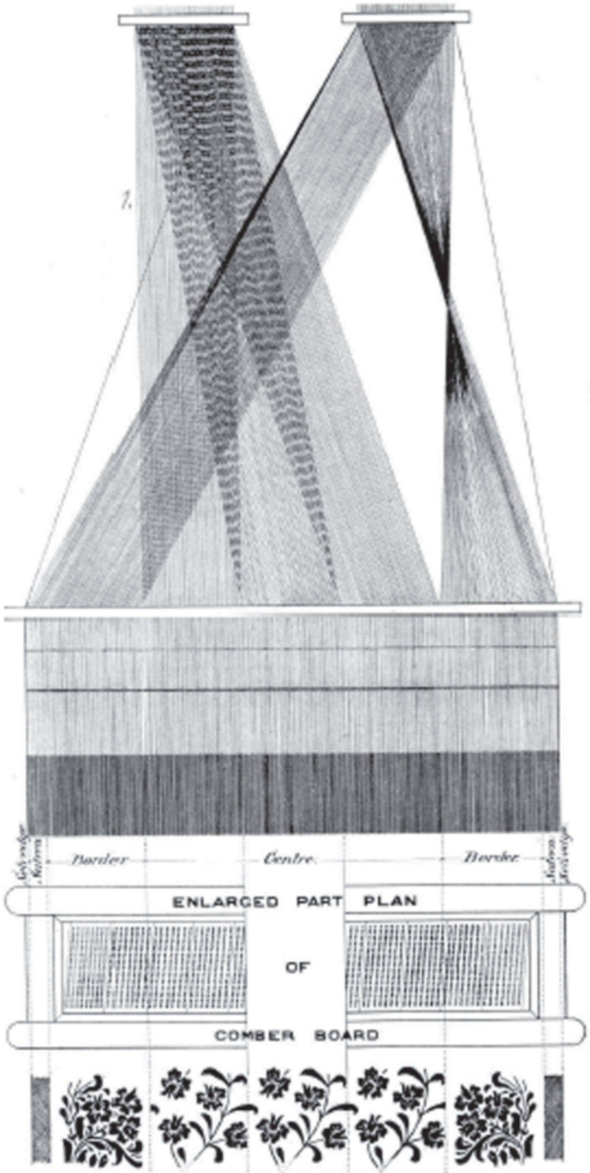

Figure 9

custom made for a particular loom/head and ***sley***, also called *sett* or EPI (ends per inch). Changing the harness' sley is not simple - if you move the heddles farther apart the path of the cords changes and their lengths must be re-adjusted.

TIS (now SAMT Development) made a loom with an ingenious arrangement of cord paths which could be adjusted for different sleys - each cord takes 2 adjustable bends which can be used to largely cancel out the changes in cord length when the sley is changed. TIS looms are used at various schools, including SCAD in Savannah GA, CEFTEQ in Quebec City, and CTCM in Montreal, but I have not yet heard of any being used in this country in an industrial setting.

Digital Weaving Norway's TC1 loom does not use a harness - instead there is a direct and straight connection from each hook to its corresponding heddle. This has both advantages and limitations.

The **huge** advantage is that the head can be mounted just a few inches above the fabric. This results in a very compact loom which can fit just about anywhere and can easily be moved around without a rigging crew.

A corresponding limitation is that, since there is no harness in the traditional sense, there is no way to create repeats with harness cords. In other words, if your TC1 is set up for 2688 ends across a 13.5" width, there isn't any way to repeat the pattern to get 27 or 54" wide cloth... Considered from the opposite direction, if you want to weave 54" wide cloth at 200 sley (ends per inch) on a TC1, you must order a TC1 set up for 10,752 hooks.

Another limitation is that the sley is determined by the TC1's mechanical design - the heddles must be directly below the hooks. Each module is built for 15 EPI, so placing 4 modules back to front will give you 4 x 15 = 60 EPI. If you wanted, say, 50 EPI, you could only achieve this by "casting out" (ignoring, not using) 10 out of every 60 hooks which reduces the hook count available for the design.

In comparison, a traditional Jacquard head with its long harness can handle any sley without giving up any hooks - although as discussed above changing the sley requires a major overhaul of the harness (except in the case of the TIS loom). TC1 looms are being used at various schools, including CCAC in Berkeley, CA, EMU in Ypsilanti, MI, Kent State in OH, and NSCAD in Nova Scotia; in the USA another half dozen are owned by individuals.

Special considerations when using harness repeats

The use of repeats via the harness introduces some further considerations. The following notes are copied from an earlier discussion relating to a specific loom in which its 384 hooks were being repeated out 6X to fill 2304 warp ends, but the underlying principles are equally applicable anytime that the design is being repeated by the harness.

When designing you will be working on a 384 end design – the maximum number of hooks built into your Jacquard - only the harness "knows" that 2304 threads are actually being controlled by those 384 hooks. However, you do have to be aware while you are designing that the harness will be creating repeats, hence seams between those repeats.

Keep in mind that the right edge of each repeat of the design butts right up to the left edge of its next repeat so the design need to be compatible across that seam. It is a good idea to "wrap" your almost finished design so that the left and right edges come together to check what will be happening along the repeat seams....

You must also make sure that your weaves "roll out" a whole number of times across that width - again so that the repeat seams don't create strange effects.

For example, suppose that a background area is weaving with an 8-shaft weft satin. This creates weft floats of 7 as in X - - - - - - - X - - - - - - -É. If the width of your design is an exact multiple of 8 then at the right edge of your figure you will have just completed a full repeat of the satin weave and will align properly to the beginning of the next weave repeat at the left edge of the pattern repeat. However, if the design width is not an exact multiple of the weave width then you will get misalignments as shown below:

Design repeat 1 —>|<— design repeat 2

X - - - - - - - X - - - - - - - |X - - - - - - - X - - - - - - - OK

- - - - - - X - - - - - - - X - |X - - - - - - - X - - - - - - - BAD

This 2nd line would result from a design width of

N*8 +2

so the design rolls out the weave

(X - - - - - - -) N

complete times PLUS 2 more ends (X -).

The design repeat of course begins over again with

X - - - - -

resulting in

X – X - - - - - - -

at the seam.

The need for weaves to fit into the design width in turn has bearing on your choice of the number of hooks to use for your designs – you want a ÒgoodÓ number, meaning one which is compatible with a wide range of weaves. Most standard loom widths are ÒgoodÓ, but when you reduce the number of hooks, perhaps because some are needed for other purposes or to weave a narrower product, you should give careful thought to the choice of that lower number.

Consider the following example:

384 is the product of 2 x 2 x 2 x 2 x 2 x 2 x 2 x 3

so any weave whose width is the product of those factors will be compatible, including widths of:

2, 3, 4 (2x2), 6 (2x3), 8 (2x2x2), 12 (2x2x3), 16 (2x2x2x2), 24 (2x2x2x3), etc.

However weaves whose width were

5, 7, 9, 10, 11, 13, 14, 15, 17, 18, 19, 20, 21, 22, or 23

would not be compatible and would create discontinuities at the repeat edges (seams).

If you reduce the number of hooks you are using for your pattern, say to 372 (2x2x3x31) for pattern, this would only allow weave widths of 2, 3, 4, 6, or 12 (plus 31, 62, 93..) while 368 (2x2x2x2x23) would only allow 2, 4, 8, 16, 23, 46.

If your design needs a wider range of weave widths then it might be better instead to drop all the way down to 360 (2x2x2x3x3x5) which would support weave widths of 2, 3, 4, 5, 6, 8, 9, 10, 12, 15, 18, 20, 24, 30, 36...

Using hooks for other functions:

Sometimes it is necessary to use some of the hooks in the jacquard head for other purposes than lifting heddles, for example:

1. weft selection : a loom that automatically inserts the weft and can choose from several different wefts (shuttles) needs to be “told” which weft (shuttle) to select. This is most flexibly done by using some of the jacquard hooks as “weft selectors”. Some mechanisms use 3 or 4 hooks to select from 8 shuttles, most use 8 hooks (one per shuttle).
2. regulation : looms advance (take-up) the fabric after each weft insertion. Sometimes is it desired to inhibit this automatic advance on certain picks and a hook is set aside for this purpose (called the Regulator).
3. other purposes - to control special loom mechanisms used to, e.g., form pile loops, weave fringe, adjust the fabric advance, etc.
4. selvedge: you often want to weave a selvedge along each side of the fabric - a special weave designed to hold the edge together. Some looms include cam operated heddles to weave the selvedge. When you need a selvedge and you don’t have a special mechanism to weave it, then you will need to set aside a few hooks for that purpose.

With the mechanical Jacquards these functions could only be controlled by using actual hooks. Electronic Jacquards have added a new wrinkle as most support ÒElectronic FunctionsÓ which are ÒhooksÓ that don’t actually show up in the head as physical hooks. Bonas controllers always include 32 of these in positions 1..32 (the first real hook is #33) while Grosse controllers optionally include 64 to the right of the last real hook. Staubli controllers optionally include 32, positioned either to the right or the left depending on your preferences.
These ÒElectronic FunctionsÓ are electronic signals which can be hooked up to the loom, but only if the loom is capable of handling them.

It can be a bit confusing – for example a standard 2688 hook Bonas head actually provides 2688 real hooks plus 32 electronic ones for a total of 2720. In other words you will see 2688 hooks to which you can tie cords, but your electronic “cards” will each contain 2720 “hole locations” (bits).

If you mount that Bonas head on an older mechanical loom (which does not accept electronic signals) you will have to use some of the 2688 real hooks to control weft selection, etc., and you will have fewer than 2688 left for controlling the warp.On the other hand, if you mount the same Bonas head on a modern loom that can use electronic signals, and you install the appropriate cable between the Jacquard controller and the loom, then all 2688 actual hooks will be available for warp ends.

Trends in Jacquard technology:

The development of Jacquards which rely on electronic (computer) information rather than actual punched cards or paper has greatly reduced the costs of the equipment, materials and labor required to convert a design into "ready to weave" condition. It has obviated the need for expensive punch mechanisms and the time and materials costs of creating punched paper. Recent Jacquards can connect to digital networks, such as Ethernet, thus permitting direct transfer of patterns from the design computer and eliminating even the need for floppy disks.

Designs which would have taken a month to prepare in the 1970s using a manual punch could, by the 1980s, be done in a day using a high speed computer controlled punch and can now be done in minutes with direct electronic transfers. Manual punching required many minutes per card, computer controlled punches required only 1 second per card (say an hour for a 3000 pick design) but still needed time consuming post-processing for splicing into a loop and adding hangers. Transfer via floppy is a matter of a few minutes and direct transfer by networks takes only seconds for an entire job.

This has made dramatic changes in the economics of production. When a man-month of effort was required to prepare a design one had to plan on weaving many thousands of yards of that design to recoup design costs; consequently designs were few in number and conservative in nature. Now there are mills which specialize in producing small yardages, in some cases just a few yards.

The number of Jacquard hooks per mechanism has been steadily increasing from around 1000 in the 19th century to over 12,000 at the end of the 20th. In large part this too has been made practical by the above mentioned conversion to electronics.

Punched paper suffers from a number of difficulties which, though just manageable at 1344 width, would be unmanageable at 12,000 width. Also, wider Jacquards require a correspondingly increased number of ÒholesÓ to be punched (perhaps 30 million for a 12,288 x 5000 pick pattern) – slow and expensive when actual punched paper was required.

The "electronification" of the Jacquards has also helped to simplify their mechanical design – the delicate, and slow, spring-loaded mechanical sensing pins have been replaced by reliable and fast electromagnets – and thereby improved the shed formation speed.

Changes in weft insertion technology have also had a major impact on speed. The early shuttles were heavy, hence slow, and needed frequent exchanging as they ran out of yarn. Shuttle-less techniques, including rapiers, projectiles, water-jet and air-jet, have vastly increased the speed and reliability of weft insertion. Speeds have changed from a few dozen picks per minute for a hand loom, to a hundred or more with a power loom, to as high as 800 picks per minute for recent Jacquard equipped looms (and thousands per minute for plain looms).

The simplification of Jacquard mechanisms has reduced the cost per hook of manufacturing a Jacquard which has meant lower purchase costs, especially since the electronic versions no longer require support equipment such as punches. This in turn has made possible the reemergence of the hand-loom Jacquards, such as the TC-1 and TIS/SAMT systems. Though by no means inexpensive, these new mechanisms have brought Jacquard technology well into the reach of schools and even of some individuals.

All these developments have greatly increased the accessibility of Jacquard designing. Jacquard design was largely the sole province of large mills when it required massive and expensive equipment and the skilled manpower to maintain it. With design preparation generally a critical bottleneck – large amounts of time required on expensive, hence rare, equipment – there was little room for ÒoutsiderÓ access nor short-run jobs.
It is now possible to perform the entire design and preparation for weaving on a personal computer, even a lap-top, and to then transfer the ready-to-weave file via email to a mill. In turn, the mills have become capable of profitably weaving small yardages at reasonable costs. Finally, a growing number of schools are able to offer Jacquard training, either on their own looms or by contracting out the actual weaving through a commercial mill.

All the above has set the stage for an explosion in designers and designs – **we should be entering the Golden Age of Jacquard design.**

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