A Modern Automated Machine Quilting System

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ABSTRACT

A quilt is a fabric item, often in the form of a bed covering, with two fabric layers between which is a layer of insulating "batting". In one style, the three layers are held together by a pattern of continuous stitching, a process known as *quilting*. This may be efficiently applied by a quilting machine, in which a sewing machine ("sewing head") travels on a bidirectional carriage system over a portion of the entire quilt. In an automated machine quilting system, the sewing head is driven by a computer-controlled servo system so as to automatically execute the desired pattern. In this article we describe a modern automated machine quilting system utilizing a newly introduced sewing head and a mature commercially-available PC-based computer control system.

BACKGROUND

Quilts

A quilt is a fabric item often intended for use as a bed covering, but which we may often find used as a "lap robe" or even as a decorative wall hanging.

A quilt comprises two fabric layers (the "top" and the "back") between which is sandwiched a layer of insulated batting, typically cotton, polyester, or wool, or a blend of these.

The top is ordinarily decorative. It may be made of a single piece (or only a few joined pieces, if needed to provide the desired width, or to implement a border) of printed or dyed fabric, spoken of as "whole cloth" construction.

More commonly, the top is "pieced": composed of numerous small pieces of cloth of various colors or patterns, sewn together. A complex pieced top may comprise several thousand individual pieces. The piecing may either be done by hand stitching or with a sewing machine. Sometimes embroidery or appliqué work is included on either a whole cloth or pieced top.

The back is ordinarily of whole cloth construction, although rarely a pieced back is used as well.

The quilt is usually held together by one of two techniques:

- The quilt may be "tied", held together in numerous places with lengths of thread, cord, yarn, or ribbon passing through the quilt and tied, usually with the free ends extending for decorative effect.

- The quilt may be "quilted", held together by through stitching, usually in a decorative pattern, extending across its entire surface. (Thus we encounter the dual usage of the word "quilting", both (a) meaning the overall process of making a quilt and (b) meaning the stitching used to hold the quilt together and the process of applying it.) The quilting process is a major component of the overall artistic content of a completed quilt.

Quilting can be performed in several ways:

- By hand with the quilt in the lap of the artisan, on a table, or held by a "quilting frame".

- On a conventional sewing machine. This is only practical for small quilts, since to stitch in the interior of the quilt a substantial amount of the surrounding fabric needs to be rolled up or folded within the throat of the sewing machine.

- On a quilting machine, on which a sewing machine (often called here a "sewing head", and often of a special design) moves across the quilt on a bidirectional carriage. We will discuss this mode in detail in the section to follow.

The quilting machine

A quilting machine comprises two major portions, the quilting machine frame and the sewing head. The three fabric layers of the quilt, the top, back, and batting, are each rolled up on a long tubular spindle.[1] [2] The spindles are mounted across the front of the frame. A fourth spindle, on which the completed quilt will be progressively wound, is mounted toward the rear.

The sewing head is on a bidirectional carriage, which can move across the entire width of the quilt on the frame and as well from front to rear over a modest distance. The takeup spindle is within the throat opening of the head.

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[1] Often called "rollers", "tubes" or "poles"

[2] Sometimes the batting is just piled on the floor or on a shelf under the frame, or pulled from a "mill roll" on an axle under the frame.

The head is guided, either manually or automatically, to stitch a "swath" of the pattern extending across the width of the quilt. When one swath is finished, some of the completed portion of the quilt is rolled onto the takeup spindle, drawing additional fabric from the three supply spindles.

The movement of the head in the fore-and-aft direction is limited by the presence of the takeup spindle, with its roll of completed quilt, within the throat of the head. As the process nears its end, the roll of completed quilt may attain a diameter of 4" or greater. For a sewing head with a nominal throat depth of 9" (typical of even larger-size "domestic" sewing machines, often used as sewing heads), the motion may be limited to perhaps 3-1/2". Thus, each swath can only embrace perhaps 3-1/2" of pattern. This essentially precludes the use of patterns with large motifs.

To mitigate this limitation, it is desirable to use sewing heads with greater throat depths. Some industrial sewing machines are employed, as well as special sewing heads specifically designed (or adapted) for machine quilting use. These having a throat depth of perhaps 18" or greater are called "long arm" machines. Throat depths up to 30" can be found in this class.

Recently, there is increasing use of so-called "mid-arm" sewing heads, whose throat depth is in the range of perhaps 15"-17".

Following the pattern

There are a number of ways in which the pattern for the quilting can be followed. The artisan may just do it "freehand", following the sewing on the finished quilt. (The sewing head and carriage are ordinarily equipped with "handlebars" for controlling the motion.)

In some cases, the artisan may mark the pattern on the face of the quilt top, using chalk or a marking pen whose marks can be washed away.

Often, the quilting machine will have a long shelf on which a full-scale paper pattern is placed. An arm connected to the head or carriage carries a stylus, a transparent "cursor", or a laser pointer. The artisan guides the head so this pointer follows a line on the pattern. This is sometimes called "pantograph" work, the term referring to the overhead arm used to support the pointer.

Sometimes the pattern shelf is above the head. This allows the artisan to work from the front side of the machine. In other cases, the shelf is placed at the rear of the frame (at "desktop" level). This requires the artisan to conduct the quilting work from the rear of the machine, and of course requires that there be sufficient space behind it to do so.

This is generally considered a less-convenient arrangement than the overhead pattern shelf.

Machine quilting frames

There is a wide variety of designs used for machine quilting frames. A number of frames are made of plywood. Others are made of aluminum, while some of the larger frames have steel members.

Mid-arm sewing heads

Various sewing heads in the mid-arm range (throat depth of perhaps 15"-17") are available. Some have been designed specifically for this purpose. There are also shops that specialize in taking a domestic or commercial sewing machine and "stretching" it to a larger throat depth. This involves cutting through the casting that comprises the upper arm and machine bed (that entire component is sometimes spoken of as the "harp" of the machine) and inserting custom-made extension sections.

The various shafts, rocker arms, and the like that pass through the arm and the bed to the needle-end mechanisms are then also extended by cutting through them and welding in extension sections. The feed dogs of the machine are not used in machine quilting applications, and so often they, and the various shafts and arms that drive them, are just jettisoned.

OUR EARLIER SYSTEM

In 2003, my wife Carla returned to quiltmaking, a craft she had enjoyed earlier in her life. She decided to make quilts for all of our children, grandchildren, and great-grandchildren. She designed and pieced her first quilt, and had it quilted by an artisan at a local quilt shop. But we soon decided that we would rather be self-contained in that regard, so we began looking into machine quilting systems.

After considerable research, we decided to base our system on a NewJoy "Gold Standard" machine quilting frame, made by NewJoy Quilting Products, Inc., of Glendale, Arizona. This is a well made, all-aluminum frame suitable for use with heads having a throat depth of up to perhaps 9".

As our sewing head, we acquired a Juki TL-98E commercial sewing machine, with a nominal throat depth of 9". (This is a machine that might be used in a tailor shop.) Among its other features, this machine has an electric thread cutter, which will cut both threads at the end of a sewing pass and retain the end of the bobbin thread so that another sewing pass can be started without need for any further attention to the thread.

We assembled the system, and shortly made some small improvements. We placed a control button for the thread cutter on the carriage "handlebar" ([3]).

We also added a presser foot interlock switch. This prevents starting the head motor if the presser foot has not been lowered. (Doing this would inevitably and immediately result in a dreadful thread tangle.) Most modern "domestic" sewing machines include this feature, but commercial machines generally don't (as tailors and the like are supposed to have enough skill to avoid the problem).

Figure 1 shows this system.

Figure 1. NewJoy Gold Standard frame and Juki TL-98E head

This system served us well, and Carla completed about 40 quilts on it over the years.

However, because of the limited head stroke (and thus the limited width of one pattern swath), the task of quilting was rather tedious, and Carla's objective was not just to spend time—rather, it was to design and make quilts.

So we decided to look into a system with a mid-arm head and a fully automatic pattern sewing capability. Thus began the adventure this article reports. It took us through art; science; mechanical, electrical, and software engineering; laboratory and machine shop work; and many other disciplines.

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[3] The button on the head itself is on the side, toward the "handwheel" end, not handy to reach during quilting operation. When using the machine for normal sewing, there is also a foot pedal for the thread cutter adjacent to the foot speed control, but of course this was of no use in the machine quilting situation.

THE NEW SYSTEM

Introduction

After considerable research, we decided to assemble a machine quilting system from these subsystems:

- Frame. The frame is a Magic frame, made by NewJoy Quilting Products, Inc. (introduced in 2007). This frame is suitable for work with heads having throat depths up to perhaps 18", and can be assembled to an overall spindle width of 12'. It is of heavy-duty aluminum construction, and provides for an overhead pattern shelf (or a "gallery" shelf at table level behind, if that is for some reason preferred).

- Sewing head. The sewing head is a Crystal Quilter head, made by NewJoy (introduced in spring of 2008). This head has a throat depth of 16" and is equipped with an electric thread cutter, an automatic needle threader (another feature pooh-poohed by old-time quilters, who never had them on their sewing machines either), and a presser foot interlock. This machine uses the stitching and drive mechanisms of the Janome 1600P commercial sewing machine, mounted in a longer housing designed for the purpose.

- Automation system. This is a PC Quilter Model SF computer controlled quilting system, made by Quilting Technologies of Port Townsend, Washington. This system comprises a two-axis servo-driven carriage that replaces the normal carriage on the machine quilting frame. A controller in the carriage interfaces with a user-supplied PC, which serves as the processor host, running a specialized suite of software. We will describe this system in some detail as we go.

- Host computer. This is a Dell Latitude D600 laptop computer (1.6 GHz clock speed), with 512 MiB of memory.

To the best of our knowledge, as of this writing (October, 2008) this is the first mating of the PC Quilter automation system to the NewJoy Magic frame and the NewJoy Crystal Quilter sewing head.

Adaptation of the PC Quilter automation system

The PC Quilter (PCQ) automation system has evolved over a number of years, and the product line includes a number of different arrangements. It is intended that the package be adaptable to a wide range of quilting machine frames and associated sewing heads.

There are two basic physical configurations. In one (the "basic" family), the servo-controlled carriage that is the heart of the system replaces the normal carriage on the machine quilting frame to be used.

In another (the "side-mount" model), used especially in long-arm systems, the existing carriage is retained, and the PCQ system works through an auxiliary servo-controlled carriage mounted alongside the main carriage and mechanically coupled to it.

The basic PCQ carriage comprises a lower carriage and an upper carriage. The upper carriage moves in the fore-and-aft direction (the Y-axis) on ball-bearing steel wheels running on rails on the lower carriage. It is driven by a stepping motor working through a toothed belt attached to the upper carriage.

The lower carriage is moved left-to-right (the X-axis) along the rails of the machine quilting frame, and thus must be adapted to the frame construction involved. Again, drive in this direction is by way of a stepping motor, operating on a toothed belt extending the full width of the frame.

The PCQ carriage "out of the box" has a set of ball-bearing X-axis wheels at a fixed spacing. In some machine quilting frames, the left-to-right travel is along simple rails (reminiscent to those on which a sliding patio door runs) fastened to a tabletop (perhaps a folding "banquet table") with clamps (sometimes even carpenter's clamps—how agricultural!). In some such cases, the rails can be shifted in their location until they match the preordained wheel spacing of the stock PCQ carriage, and that is all there is to it.

More commonly, though, these "default" wheels are removed and the PCQ carriage fastened to a mechanical adaptation assembly that carries wheels of appropriate design and spacing running on the tracks of the frame. Many major frame manufacturers offer PCQ adaptation kits for their frames. NewJoy, for example, offers such a kit for their Gold Standard frame, and is likely developing one for their new Magic frame. However, it is not yet available. Accordingly, we designed and had fabricated an appropriate carriage adaptation assembly (which we will describe at length shortly).

Sewing head motor control by the PC Quilter system

The PCQ system offers many modes of control of the motor of the sewing head, as needed to accommodate a range of heads. The system never "dynamically" controls the head speed. It does not, for example, increase and decrease the head speed during sewing of the pattern. Rather, the *modus operandi* depends on moving the carriage at a constant velocity, so that with the head running at a constant speed (in terms of number of stitches per second), the stitch length in the quilting will remain constant.

Nevertheless, in some situations, the way in which the PCQ system starts the sewing head motor also requires that it control the speed,

but only in the sense of putting into effect a fixed speed that is preselected by the user.

One interface offered by the PCQ system for head motor control (start-stop only) provides a 12 V signal on an interface jack. In one mode, the signal is on when the motor is to run and off otherwise. In another mode, a short pulse of the signal is provided when the motor is to start and another short pulse when it is to stop. It is this interface in the latter mode that we exploit in our installation.

Carriage stroke, resolution, and speed

The carriage of the PCQ SF system has an overall Y-direction stroke capability of 15.1". The usable stroke is of course constrained by head throat depth considerations. The X-direction stroke is determined by the width of the frame and the overall carriage dimensions. In our system, the full X-direction stroke is 106.5".

The stepping motors use in the PCQ system have 400 full step positions per revolution, The drive sprockets have a pitch diameter of 1.4324" (a pitch circumference of 4.5000"), and thus the "full step" resolution of the carriage in each direction is 0.01125". The control system allows positioning in terms of half steps, giving an ultimate incremental resolution of 0.005625".

The carriage travel speed to be used for a particular task is chosen from a set of 7 predefined speeds (the specific speed values associated with each "step" being defined by a table in the initialization file). The fastest practical attainable speed is 2.25 in/sec. Our system is programmed for this as its top available speed.

In practice, considerations of head and carriage dynamics suggest that a nominal speed of perhaps 1.25 in/sec is about the fastest that should be used.

In operation, the same speed occurs regardless of the instantaneous track direction (the velocity vector has a constant magnitude), resulting in a consistent stitch length (for any given stitching rate by the head).

PC Quilter flexibility

As a result of its long history of adaptation to many different system configurations, and for use by artisans with a wide range of needs, the PCQ system is extraordinarily flexible. Some might call it "nerd-oriented", and in fact, when one places an order for the system, one must undergo a brief computer literacy evaluation by the Quilting Technologies technical support desk!

Many system parameters are set by entries in an initialization file, and all are discussed in considerable detail in the system documentation.

PC QUILTER OPERATION

PC Quilter user interface

In its earliest manifestation (2001), although the PC Quilter software operated under Windows, it was operated by the user from the host computer via a DOS-like character-mode serial interactive dialog (sometimes called a "console interface", by reference to early computer consoles, in which the operator interacted via a keyboard and a printer). This is described in the PCQ literature as the "command line interface" (CLI) form of control. That term is, however, inappropriate for this mode.[4]

The motivation for this (in 2001) seemingly-primitive user interface was to permit operation on PCs of very limited processor capacity— which could be acquired, used, at low cost during that time period.

In 2004, Quilting Technologies introduced a graphic user interface (GUI) "front end" for the system. This has a *bona fide* Windows user interface, and behind the scene feeds instructions to the underlying PCQ operating program. (Its top-level portion is called QTMenu.)

In 2007, Quilting Technologies introduced a color touchscreen control panel for the system. It can be, for example, mounted on the sewing head. It operates with its own "front end" software, and, like the graphic user interface package, feeds commands behind the scene to the underlying PCQ program.

There are, however, some subtleties of pattern modification and manipulation that cannot readily be done from the touchscreen (in its present version), so even if it is installed, some preparatory work may need to be done at the computer.

The PC Quilter pattern language

Pattern files for use by the PCQ system are ASCII files using a very straightforward syntax. The principal statement describes a point on

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[4] "Command line interface" implies a non-interactive mode of control of a program, in which any instructions, option settings, values, identification of files to be processed, and so forth as given as "parameters" to the command statement, submitted to the "DOS prompt", that loads and starts the program. The PCQ software is not used in that mode. The user starts it (in Windows, with a shortcut) and all other input is provided interactively in response to prompts given in a "DOS-looking" serial, character-oriented dialog. This is not a "command line interface".

the pattern path in terms of X and Y coordinates, expressed in signed decimal notation to a precision of up to 3 decimal places. The values are placed in the order X, Y, with just a space between them.

For basic operation, the origin (0, 0) is arbitrary. The first point is always executed at the physical location of the carriage when execution begins, and all other points are placed relative to the coordinates of that initial point.

The PCQ pattern language is described in considerable detail in Appendix A.

SYSTEM PLAN AND ADAPTATION

Carriage mechanical adaptation

The NewJoy Magic frame uses an unusual track arrangement for the X-direction movement of the carriage). The long rails of the frame are aluminum extrusions having an open bottom with a central septum (see figure 2). On this septum are two tracks, both upward facing (at different altitudes).
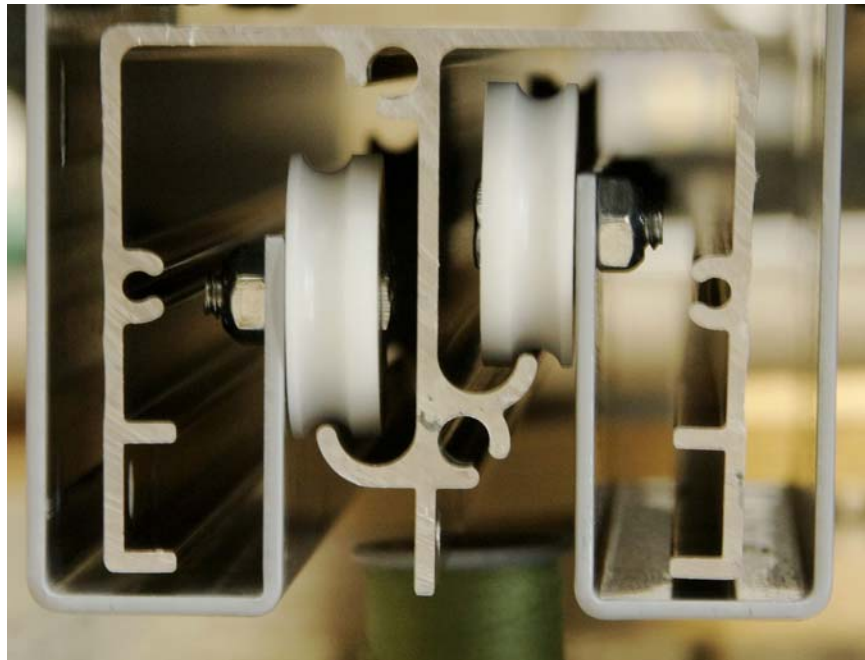
Figure 2. Magic frame rail with tracks; carriers and wheels

The carriage has, at both the front and rear ends, (that is, at each frame rail) a pair of wheel carriers (gray finish in the picture), each of which carries a pair of grooved nylon wheels, mounted on ball bearings. The hangers reach into the rails through the open bottoms of the two sides, so that all four wheels ride on the top surfaces of the tracks.

After some study, we concluded that the best approach to adaptation would be to mount the two pairs of standard wheel hangers on the ends of an adapter plate with a dropped center. The PCQ carriage would then sit into that dropped center (resting essentially on the edges of the two flanges on the carriage which in the "default" configuration of the carriage carry its X-direction wheels).

A related design issue was the positioning of the PCQ carriage along the length of the adapter plate. This had to be resolved with reference to the issue of matching:

- The possible Y-direction travel of the head on the PCQ carriage (as limited by the upper carriage wheel and drive arrangements), and

- The possible Y-direction travel of the head considering the location of the takeup spindle (the travel is limited where the throat rear, or the needle bar at the front, would strike the loaded takeup roller).

We wanted to have the excess of the former travel over the latter approximately equally divided between the two ends of travel.

Attaining this required the PCQ carriage to be located on the adapter plate in such a location that there would be interference between the rearmost extensions of the PCQ carriage side frame and the actual frame rails. Fortunately, there was nothing (much) to prevent notching the carriage side frame to get the necessary clearance.

There was some question as to how the adapter plate should be given the necessary flexural stiffness. A design with side flanges would have been ideal, but would have been costly to fabricate on a "one-off" basis. Instead, we chose to have the plate made of relatively large-gauge steel plate (10 gauge, nominally 0.1345" thick), and then to augment its stiffness over its long central span with aluminum angle ribs underneath.

After the design was completed, a local machine shop made the plate itself for us quickly, shearing the material with a really big shear ("well, it's not as big as it seems—the blade has a nick in it about two feet from the right end") and forming it with a really big press brake. We then drilled all the necessary holes, added the stiffeners, made some mounting brackets to hold the PCQ carriage in place, notched the carriage as discussed above, and put the whole works together. Sounds really simple, doesn't it!

Figure 3 shows the adapter plate itself, with the original wheel carriers attached. (The stiffening ribs are not in place here).

Figure 3. Adapter plate with wheel carriers

Figure 4 shows the adapter with the PCQ carriage in place. In the final design, the PCQ carriage is about 0.500" higher than shown here, to provide increased clearance over the frame rails). This picture also does not show the stiffening ribs.

Figure 4. Adapter plate with PCQ carriage

Carriage electrics

Some minor changes were made in the PCQ carriage wiring arrangements. The head motor control circuit was originally terminated in a coaxial power connector (like that used for electronic equipment "power bricks"). Such a connector is, in our opinion, unsuitable for a control circuit, so we replaced it with a 2-contact "Molex" connector (small body 0.093" pin series).

On the standard PCQ carriage is a toggle switch[5] used to force the system to pause so that a problem can be dealt with (thread tangles, etc.). It was mounted at the rear of the carriage (had it been placed at the front, it would have been inaccessible through the fabric sandwich). But the rear location was inconvenient for operation from the front of the system, and in any case, that space eventually became needed for a limb of the mechanical adapter plate.

Thus we brought the pause control leads out to another 2-contact Molex connector (it was distinguished from the other Molex connector by choice of housing and contact genders so the two could not be confused). This eventually connects to a switch we located on the head handlebars, convenient for operator use.

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[5] Ball handle—how's that, electrical nostalgia fans.

We also removed an electromechanical module in the carriage used for motor control in other application configurations[6] and installed in its place the power unit for the carriage (which would otherwise have just hung around outside the carriage someplace).

The original design of the PCQ system used a parallel port to connect to the host PC. Later, a serial port option was added. Today, the preferred mode of interface is via a USB port on the host (operating in a COM port emulation mode). The standard configuration is to run a serial cable to the host computer and there insinuate a USB-to-COM adapter supplied with the system.

Since we were trying to minimize the umbilical load on the carriage, we emplaced the USB-to-COM adapter directly into the COM port on the carriage controller board, and ran a USB cable all the way to the host PC. (A second USB cable runs from the touchscreen control panel, mounted on the sewing head, to the host PC.)

The interior of the modified PCQ carriage is seen in figure 5.
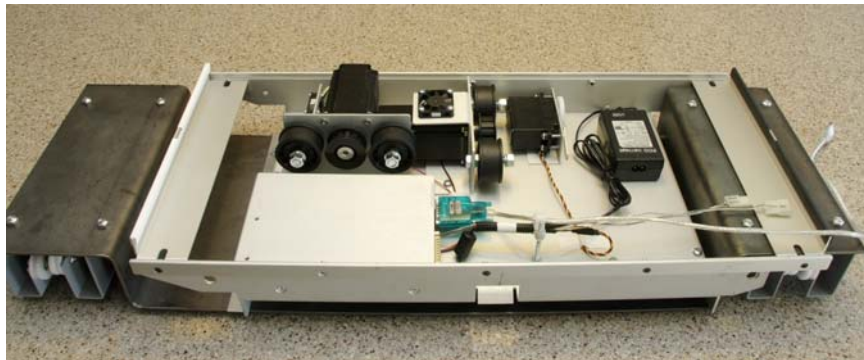
Figure 5. Adapted PCQ carriage with upper carriage removed

We see the Y-direction drive (stepping motor with sprocket and idler pulleys) on the left, and the X-direction drive in the center. (There is normally a shroud over the sprocket and pulley area of the X-direction drive to prevent inadvertent entanglement of the belt, but this was removed for the photograph.) The controller PC board is under an aluminum cover (just to the left of the transparent green "plug", which is actually the USB-to-COM interface adapter.

For the motor control function, we made an interface adapter cable (with an embedded relay) to run from the motor control jack on the PCQ carriage to an accessory connector (DE-9S, often miscalled DB-9S) on the Crystal Quilter head, where the leads from the

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[6] It uses a servomotor to squeeze the conventional foot controller for the sewing machine head—no kidding, I didn't make that up!

momentary start-stop button on the handlebars were accessible. The relay, a subminiature type, was placed in the hood of the mating DE-9P plug so no inline pod was required.

Head adaptation

Little adaptation was required to the Crystal Quilter sewing head. An auxiliary bracket was added to support the PCQ touchscreen control panel above the control panel for the head proper. The remote pause switch mentioned above was mounted on the handlebar support.

Figure 6. Crystal Quilter head on adapted PCQ carriage

Figure 6 shows the head on the adapted carriage.

Figure 7 shows the carriage "cockpit". The handlebar assembly and lower control panel are a standard part of the Crystal Quilter head. The red push button atop the right handgrip is used to manually start, or stop, the sewing head motor. The black push button atop the left handgrip is used to force the needle to go to the down, or up, position when not sewing. The position in which it is when sewing starts is the position to which it will return when sewing stops. We have calibration tables that relate this to actual stitch temporal frequency (stitches/sec).

Figure 7. Carriage cockpit

The small toggle switch seen on the handlebar frame to the left of the right handgrip is the relocated PCQ pause switch. When moved to the right, the PCQ system stops the head motor and stops carriage motion. When the switch is returned to the normal position, the user receives a menu offering various things one might want to do, including:

• Resume sewing the pattern

• Abort the run

• Cause the carriage to slowly move forward, or backward, along the pattern path, with no sewing (handy when recovering from various "incidents").

The right knob sets the head sewing speed. An arbitrary digital indication of the set speed appears on the display panel.

The left knob is reserved for an optional feature not used in this installation, generically called "stitch regulation" (Select A Stitch, for the NewJoy implementation). It is for use in "freehand" quilting, and accommodates the fact that the artisan may not move the carriage at a constant speed while traversing different features of the pattern. With this feature, the instantaneous speed of travel of the carriage is determined through the use of X- and Y-axis position encoders, and the head sewing speed varied proportionately to maintain a consistent stitch length.

Of course in our system a constant carriage speed is provided by the PCQ control system, so this feature is not useful. (It is a costly add-on, so we declined it.)

The upper unit is the touchscreen control panel for the PCQ system (also a costly add-on). Shown is an alphanumeric entry screen, in this case used to select the pattern file to be used. One can enter a partial name and touch Enter, in which case a screened file list comes up, from which the desired file can be selected by touching a very tiny button at the left of the filename (hard against the panel bezel opening—one had best have long fingernails to do this).

THE COMPLETE ASSEMBLY

Overview

Figure 8 shows about the left half of the complete system.

Figure 8. Completed system

Its overall width is 127" wide (including allowance for protruding mechanical controls) and 43" deep. A clearance of 4" is required at the rear to accommodate protrusion of the carriage and head at the limit of practical rearward travel. The spindles are 120" long. A pattern up to about 100" wide, on fabric up to about 104" wide, can be worked. (The actual frame "kit" can be used to assemble a frame 24" wider.)

The X-direction toothed belt

In figure 8, we saw the X-axis toothed belt, which engages a sprocket on the X-axis stepping motor (with two idler pulleys to provide good contact). The belt is attached to the two end frame boxes of the frame via square U-bolts. These are held with prevailing vibration-resisting nuts, allowing adjustment of the belt tension. The arrangement is shown in detail in figure 9.

The belt is bent back over the U-bolt so that the teeth on the facing sides interlock, providing a strong, stable loop. The loop is held closed

with glass-fiber strapping tape. The teeth on the portion of the belt that actually contacts the U-bolt are cut off to make a better fit.

Figure 9. X-direction toothed belt attachment

Power and cable management

Three items on the carriage require AC power: the PCQ controller and carriage drive (via a cord-ended power unit), the touchscreen control panel (via a "wall brick" power unit), and the sewing head itself. To rationalize the "umbilical" situation for the carriage, we installed a small power strip (provided, incidentally, by Quilting technologies as part of the PCQ product package) on the carriage. Its cord (lengthened from the inexplicably-short one the strip came with) is the sole AC umbilical to the carriage. The arrangement is seen in figure 10.

Figure 10. Carriage AC power distribution strip

The touchscreen panel came from the factory with a single very long umbilical, a single sheath of a very nice springy fabric loom through which ran both a long DC power cable (to its wall brick) and a USB cable (to go to the host computer.)

In our case, the power brick plugs into the power strip on the carriage, so the DC cable was stripped out of the loom sheath. We used the freed space in the sheath to carry the USB cable from the PCB controller. Thus we now have only two umbilicals to the carriage, a single AC power cord, and the dual USB cable.

Figure 11. Cord tender

We didn't care to shorten the DC cable to the touchscreen unit (the coaxial power connectors used are difficult to work with). We also had excess length in the AC power cords to the head and the PCQ carriage power supply (now located in the carriage). To manage all this excess cordage, mounted a small plastic tackle box (with a latching lid) upside down on the bottom of the carriage adapter plate (partially hidden from view by the stiffening ribs). Each compartment of it harbors the excess of one of the cords, entering through notches cut in the end walls. (Clear package tape is used to hold the cord hanks in place until the lid can be shut!) Figure 11 shows this cord tender.

LOADING SCHEMES

Two different "loading schemes" are used by machine quilting enthusiasts. The NewJoy Magic frame accommodates both (with some considerable flexibility as to the details).

The "in the well" scheme

Figure **12** illustrates schematically the scheme described as "in the well". It is characterized by the fact that the three-layer fabric

"sandwich" emerges from the bottom of the uppermost supply spindle (which in this scheme carries the quilt top fabric).
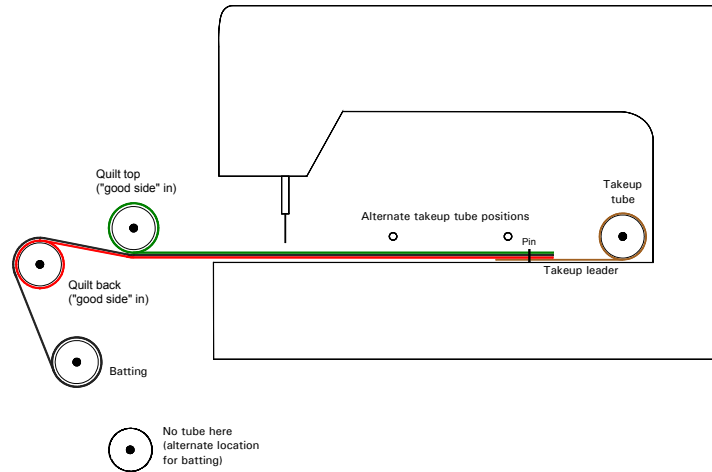

Figure 12. "In-the-well" loading scheme

The "over the top" scheme

Figure 13 illustrates the scheme described as "over the top". It is characterized by the fact that the three-layer sandwich emerges over the top of the uppermost supply spindle (which in this scheme carries the quilt back fabric).
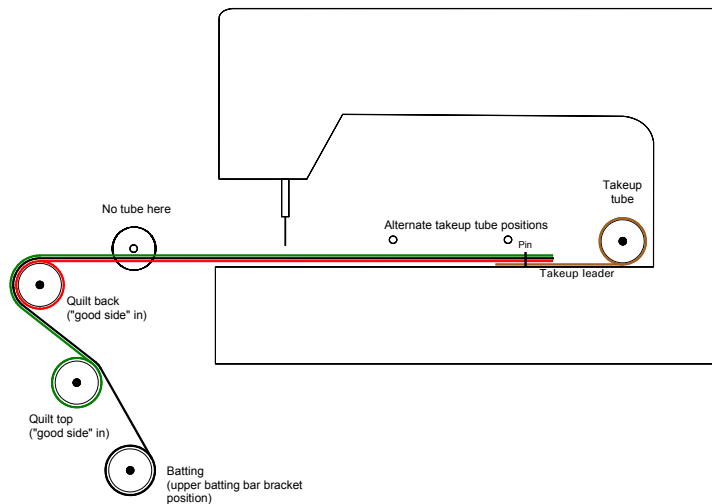

Figure 13. "Over-the-top" loading scheme

Here, the greater arc of contact of the complete three-layer sandwich with the final spindle across which it travels provides a more stable mating of the sandwich. In addition, this scheme gives the operator greater visibility of the stitching process.

This scheme does require more overall depth of the machine frame. (It is not really practical, for example, on the NewJoy Gold Standard frame we previously used.)

Batting options

Under either threading scheme, there are several options for the placement of the batting supply:

- It can be wound onto a supply spindle carried on the frame near the spindles for the top and back.

- A "mill roll" of batting (on a fiber core) can be placed on a spindle (just used as an axle) mounted near the bottom of the frame.

- It can be piled on the floor beneath the frame (or on a shelf installed there).

THE PINNING SHELF

The top and back fabric panels are attached to their respective supply spindles by being pinned to short muslin leaders, which are in turn attached to the spindles themselves with Velcro. Similarly, the leading edge of the completed "sandwich" is attached to the takeup spindle by being pinned to a short muslin leader there.

Sometimes, the supply spindles are "loaded" with their fabric panels on a floor (we call it "loft loading"). In that situation, it is easy to pin the fabric to the leader, since both lie nicely on the floor. But in many cases it is more practical to wind the fabric onto the spindles with them in place on the machine. For one thing, on the new machine, the spindles are very heavy, and as well are 10' long, so maneuvering them between the "loft" and the "studio" is not that easy. Now, pinning the fabric panel to the edge of the leader is not so simple.

In any case, the three-layer sandwich must be pinned to the takeup leader *in situ*, which turns out to be very tricky done "in midair".

In order to facilitate these operations, we have equipped the new system with a pinning shelf system of our design. This temporarily holds a narrow board of soft wood (the "pinning shelf") in place as a work surface for performing each of the three pinning operations.

Two wooden supports, which are placed on the forward frame rails near the ends of the machine, support the shelf at each of the positions where it is required. (There are actually four positions that must be accommodated, to cater for two different "threading schemes" that can be used with the machine.)

In the illustrations below, the system is configured for "over-the-top" loading.

In figure 14 we see one of the shelf supports. The surfaces that contact the frame rail have felt pads to avoid marring of the anodized rail surfaces.

Figure 14. Pinning shelf support

In figure 15 we see the left support in place on the front rail of the frame.

Figure 15. Left support in place

In figure 16 we see the shelf in place where it would be positioned for pinning the top fabric panel, carried by the second spindle from the top.

Figure 16. Shelf in position for pinning the top

In figure 17 we see the setup for pinning the top fabric (a colorful dish towel is used as a stand-in for the top panel). The good side of the fabric is oriented as shown: uppermost (it will wind toward the spindle).
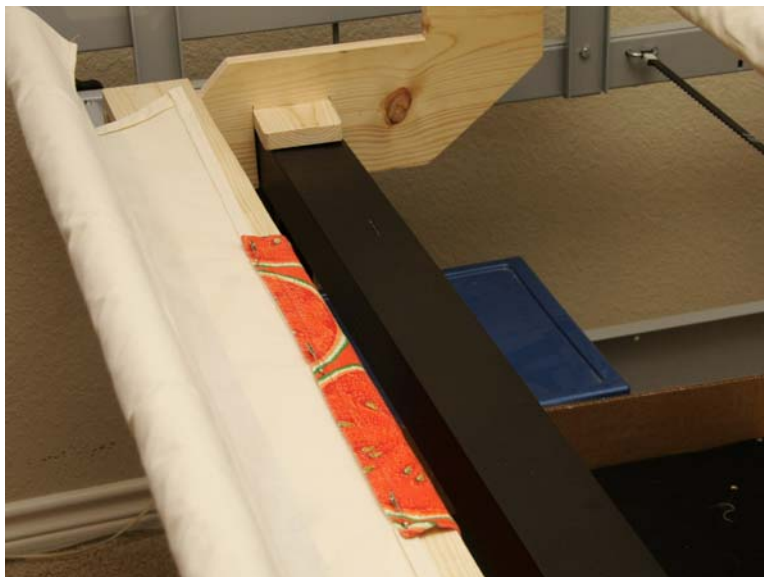
Figure 17. Pinning the top

Auxiliary support blocks are put in place (figure 18) to support the shelf at the higher altitude needed for pinning the back fabric panel, carried by the uppermost spindle. They have integral dowel pins that go into the holes in the shelf supports that can be seen in figure 15.
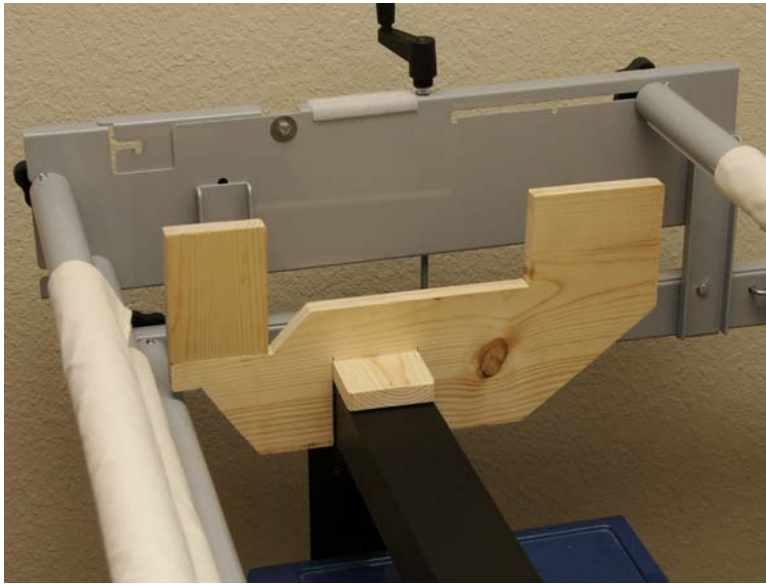
Figure 18. Support with auxiliary block in place

In figure 19 we see the shelf in place for pinning the back fabric panel.

Figure 19. Shelf in position for pinning the back

In figure 20 we see the setup for pinning the back fabric. Here, the "good" side of the fabric would actually be downward (again, it will wind toward the spindle); in the photo, the good side is up for best visual effect.

Figure 20. Pinning the back

For pinning the fabric sandwich to the takeup spindle leader, the shelf is placed in a third position (figure 21). The auxiliary block is not used at this time, but is shown in place.

Depending on the fabric widths involved, the left support may be moved inboard of the carriage so the carriage can be moved fully to the left, clearing the working zone. (For the back and top pinning, it may not be possible to have the support so far inboard, as the fabric needs to be brought over the rear of the shelf. But for those operations, it is not obtrusive for the carriage to be parked within the fabric width.)

Figure 21. Shelf in position for pinning sandwich

In figure 22 we see the setup for pinning the sandwich to the takeup leader.

Figure 22. Pinning sandwich to takeup leader

FREE-MOTION OPERATION

With the drive to the carriage stepping motors inactive ("carriage unlocked" state), the carriage can be moved fairly easily by hand. There is some drag from the friction of the toothed belts over their sprockets, and the motors impose a subtle "detenting" at a spatial frequency of about 89 "ticks" per inch.

This notwithstanding, it is perfectly practical to engage in limited "free-motion" quilting, as might be needed to join together automatically-worked pattern sections, or to repair lapses in the automated stitching caused by technical mishaps.

But the behavior isn't really suited for extensive free-motion work (sewing a whole quilt under hand control from a "pantograph" pattern, for example).

In any case, Carla has no intent to engage again in extensive free-motion work.

Accordingly, we have not installed the pattern shelf on the frame.

CONCLUSION

By "straightforward" integration of new subsystems from experienced providers, we have in a relatively short period put together and commissioned a highly-capable automated machine quilting system. We look forward to the projects it can help us complete.

ACKNOWLEDGEMENTS

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APPENDIX A

PCQ Pattern Files

The pattern file

The patterns to be worked through the PCQ system are described in pattern files. They describe the "path" of the figure in terms of discrete points. The PCQ software reads this path description and fits a curve to it, and then gives incremental instructions to the carriage stepping motors to follow that curve with a resolution of about 0.01" (about 0.005" in one mode).

Basic syntax

Pattern files for use by the PCQ system are ASCII files using a very straightforward syntax. The principal statement describes a point on the pattern path in terms of X and Y coordinates, expressed in signed decimal notation to a precision of up to 3 decimal places. The values are placed in the order X, Y, with just a space between them.

For basic operation, the origin (0,0) is arbitrary. The first point is always executed at the physical location of the carriage when execution begins, and all other points are placed relative to the coordinates of that initial point.

Thus this file (shown in its entirety) would result in the system sewing a 5" x 5" square (in a counterclockwise direction beginning at its near left corner):

    0 0

    0 5

    5 5

    5 0

    0 0

The lower left corner of the square (represented by the first point entry) would be located at the initial carriage position.

Because of the relative nature of the coordinate system, the following file would generate the same stitched pattern in the same place (assuming identical initial carriage locations):

    1 3

    1 8

    6 8

    6 3

    1 3

However, there is a potential significance to the difference between the two, because when the basic pattern is modified under control of specialized commands placed in the pattern file, or entered by the user on the "control panel" in preparation for execution, certain transformations are made with respect to the origin (0,0), and hence their impact varies with the location of the origin with respect to the pattern figure.

Discontinuous patterns

In some cases, it is not appropriate or practical to have continuous stitching for the entire pattern. In that case, an interruption to movement of the head along the path can be made, allowing the user to cut the thread (hopefully, by just punching a button!) and then having the system automatically move the carriage to the proper place to resume stitching. Locations where this should occur are signalized with the Jump command in the file.

For example, this file would sew two concentric squares:

    -2 -2

    2 -2

    2 2

    -2 2

    -2 -2

    jump

    -1.25 -1.25

    1.25 -1.25

    1.25 1.25

    -1.25 1.25

    -1.25 -1.25

Here, for symmetry, I arbitrarily use the center of the two squares as the numerical origin (0, 0). Nevertheless, as always, the first point (whose coordinates will be considered to be -2, -2) will still be at the initial physical position of the carriage.

Controlling the initial position relative to a benchmark

We may want to locate each "pass" with respect to some point on the previous pass, or to some feature on the quilt top, such as a boundary between blocks. We can easily do that by means of an "initial jump" (called, for historical reasons, a "courtesy jump" in the PCQ literature).

Suppose we wanted the "single 5"x5" square" pattern we saw earlier to be executed such that the lower left corner of the pattern (the first point of the pattern) fell exactly 6 inches below the corresponding corner of the pattern just sewn. Then we would use this file:

```
0 6

jump

0 0

0 5

5 5

5 0

0 0
```

We would place the sewing point (needle cursor) on the lower left corner of the previous pattern and execute the file. The first statement in effect defines that initial physical location of the carriage as having coordinates 0, 6. However, the jump command immediately following tells the system to not start sewing at that point but rather to move to coordinates 0, 0 (in our example, the desired location for the lower left corner of this "pass")—6 inches below the initial point.

The head would then be started and the carriage would commence its movement over the pattern.

Pattern modification

The PCQ system allows the user to start with a pattern defined by a file and make many kinds of modifications or adaptations to it. These include:

- Scaling it in the X- and or Y- directions.

- Replicating the pattern in the X- or Y- direction (but not both). For replication in the X-direction, a controllable blank space can be included between the instances.

- Rotating the pattern through an arbitrary angle. [Note 1]

- "Flipping" the pattern about the X- or Y- axis or both. [Note 1]

- Adding "mirrored" instances of the pattern about either axis (or both). [Note 1]

- Making multiple "radial" instances of the pattern (*e.g.*, turning a "petal" into a "flower"). [Note 1]

- Offsetting the pattern along the X-axis (essentially, starting at some point along its width, and adding the omitted portion back in at the far end). [Note 2]

- Skewing the pattern by shifting the right and/or left sides of its bounding box up or down, or shifting its top and/or bottom edges to the right or the left, or both.

- Trimming a defined portion off the top, bottom, left, or right edge of the pattern. [Note 2]

   Note 1: These operations require that the origin of the pattern coordinate system be appropriately located with respect to the figure.

   Note 2: These operations will usually result in a bunch of "loose ends" of the pattern line at the new boundary; the program will connect these together in the best way possible to allow the pattern to be stitched on a "continuous line" basis.

These modifications can embedded as commands in the pattern file itself (so that they will be applied whenever that file is loaded), or they can be entered during a session by the user "on the control panel", in which case they will be applied "on the fly" during the session. In the latter case, the user can call for a new pattern file to be written, in which commands describing the modifications will be embedded.

If there are pattern modification commands embedded in the pattern file as loaded, the user may modify their parameters or suppress them from the control panel for this session.

Pattern file creation and editing

Pattern files are often generated by special software operating from a graphic image of the desired figure (either drawn with a computer-based drawing system (perhaps even a CAD system) or scanned from a hand drawing or in image from a publication.

The result of this "digitization" often requisite (or deserves) some further adjustment to optimize the pattern description, suppress undesirable artifacts of digitization, and so forth. Many pattern digitization software packages provide special features for this.

File descriptions may also be edited (neonatally, or later, by a user) with any handy text editor. Of course, it is not always simple to know how to turn a desired change in the shape of the figure into a modification of the set of points that describe it.

In fact, the PCQ software suite, in its graphic user interface form, includes a text editor for this purpose (although it can be disabled in the system Preferences settings). It is often used to insert, delete, or amend embedded pattern modification commands, or to make minor changes in point coordinates.

Virtual execution

A pattern file that has been loaded, subject to any modifications that are in effect, may be actually executed, causing the resulting pattern to be stitched. Alternatively, the user may invoke the "Draw" mode, in which a "virtual execution" is done.

At the completion of this virtual execution, the user is invited to see a graphic plot of what the stitching would have been, in order to be certain that the desired result will be obtained when the pattern is actually executed.

Result files

After either an actual or a virtual ("Draw") execution, two result files are written. The first (in .BMP form) is the graphic presentation of the executed "path". Each pixel of this image corresponds to an instantaneous carriage position, and the pixel pitch corresponds to thee carriage position increment.

The second is a new pattern file in standard syntax in which all modification commands have already been applied. This file thus contains no modification commands, but is rather a collection of points that, if executed, will directly produce the complete modified pattern result. (It is reminiscent of a machine language listing of an assembled program, with macros expanded and relative addresses resolved.)

Layout assistance

The PCQ software package includes a capability (called "Math Help") that will assist the user in such tasks as fitting pattern figures to the available space on the quilt. For example, the user may have a pattern module that (in native form) has a width of 10.000", and is set up so that multiple instances can be seamlessly joined to make a wider figure.

Perhaps the desired width of the entire pattern is 95.300". The user can present Math Help with this problem. The program will suggest that the user choose between:

• Having 9 instances of the figure joined, each scaled to 105.88889% of its native size (10.588889" wide), or

• Having 10 instances of the figure joined, each scaled to 95.3% of its native size (9.53" wide)

After the user makes a choice and confirms that this is the plan to be followed, the program adopts the appropriate number of instances and scaling factor for the session, and applies them during execution.

If desired, the user may cause a new pattern description file with those parameters embedded, which can then be called up directly (for example, if the work is done in separate sessions).

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