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DESIGN OF A WIRE TENSIONING DEVICE

August 1973

Bendix Corporation
Kansas City, Missouri

MASTER

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DESIGN OF A WIRE TENSIONING DEVICE

Published August 1973

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Topical Report

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DESIGN OF A WIRE TENSIONING DEVICE

Prepared by J. O. Bradley

An experimental pneumatic wire tensioner and a frictional wire tensioner were fabricated and evaluated with respect to the requirements of weaving AWG 33 magnet wire into 90-conductor tape. The frictional tensioner, redesigned to reduce variations in wire tension, is expected to provide reliable control over the wire-weaving process when incorporated into a creel.

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CONTENTS

Section	Page
SUMMARY	9
DISCUSSION	11
SCOPE AND PURPOSE	11
PRIOR WORK	11
ACTIVITY	11
<u>Woven-Wire-Tape Requirements.</u>	11
<u>Warp-Wire Tensioning</u>	12
ACCOMPLISHMENTS	24
FUTURE WORK	24
APPENDIX. DEFINITION OF WEAVING TERMS	25

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ILLUSTRATIONS

Figure		Page
1	Pneumatic Tensioner	13
2	Frictional Tensioner	14
3	Wire Tension Variations as a Function of Time	16
4	Frictional Tensioner With Feedback	19
5	Ratio of Static to Dynamic Wire Tension Versus Ratio of Static to Dynamic Coefficients of Friction	23

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SUMMARY

The purpose of this project is to design an economical and reliable method of tensioning individual warp wires during the weaving of 90-conductor wire tape.

Previous experience of Bendix Kansas City and of weaving vendors had indicated that precise control of the weaving process would be necessary to reliably weave 90, individually insulated, AWG 33 magnet wires into a tape 0.900 inch wide (22.9 mm) by 100 to 300 feet long (30.5 to 91.4 m). Precise tensioning of each warp wire has been identified as a requirement to assure continuity of all conductors and sufficient electrical isolation between adjacent conductors within the wire tape.

The warp-wire tensioning requirements and limitations were studied, and prototype pneumatic and frictional tensioners were fabricated and evaluated. The pneumatic tensioner proved to be unsatisfactory, but the frictional tensioner showed promise and was redesigned to reduce variations in wire tension. The redesigned tensioner is expected to provide reliable control of the warp wire during the weaving process.

Future activity is expected to include the fabrication and prove-in of creels incorporating 90 frictional tensioners. It is planned for these creels to be used in conjunction with vendor looms to weave wire tape. This tape in turn will be used to fabricate simulated production units which will be subjected to thermal cycling. The continuity of the warp wires and the insulation resistance between adjacent wires will be monitored to verify that the wire tensioners are providing adequate control of the weaving operation.

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DISCUSSION

SCOPE AND PURPOSE

The intent of this activity is to design an economical and reliable method for tensioning individual warp wires during the weaving of 90-conductor wire tape. After reviewing the requirements of the weaving operation and other tensioning techniques presently used, two tensioning concepts were considered. Prototypes of a pneumatic and a frictional tensioner were fabricated and evaluated. The frictional tensioner was redesigned to reduce variations in the wire tension. Definitions of weaving terms are contained in Appendix A.

PRIOR WORK

Previous activity on this project has included the following studies to assist vendors in developing the processes and equipment necessary to reliably weave 90-conductor wire tape:

- The evaluation of technical literature concerning woven-wire tape;
- The evaluation of the weaving process as related to the specific requirements of woven-wire tape;
- The evaluation of a vendor market survey; and
- The status of the existing sources of woven wire tape.

ACTIVITY

Woven-Wire-Tape Requirements

The need for a wire-tensioning device arises from requirements for the woven-wire tape being fabricated. This tape consists of 90, individually insulated, AWG 33 magnet wires woven at 20 picks per inch with 00-nylon-fill thread in a one-by-three basket-weave pattern. This produces a tape 0.900 inch wide (22.9 mm) and less than 0.016 inch thick (0.41 mm), which varies in length from less than 100 feet (30.5 m) to greater than 300 feet (91.4 m).

It is necessary that each of the 90 warp wires be electrically continuous and that the insulation resistance between all even wires tested against all odd wires be greater than $1\text{ G}\Omega$ when tested at 500 Vdc for 3 minutes. In addition, it is desirable that the elongation of the warp wires and the physical degradation of the wire insulation be held to a minimum. Previous experience has indicated that precise control of the tension on each warp wire is necessary to meet the above requirements. It has also been found that variations in the warp-wire tension can adversely affect the width of the wire tape, the stability of the weave pattern, and the handling characteristics of wire tape in subsequent processing operations.

Warp-Wire Tensioning

The evaluation of the warp-wire tensioning systems used by the three development sources (Carolina Narrow Fabric, Woven Electronics, and Bendix Kansas City Division) indicated that none of the tensioning systems was completely adequate for production weaving. It was believed that the production tensioning system should meet the following requirements:

- Provide tension on each wire in the range of 0.1 to 0.5 pound-force (0.445 to 2.22 N);
- Tension each wire independently;
- Make the tension independent of wire spool size;
- Eliminate the need to adjust the tension setting to compensate for wire consumption;
- Make the dynamic tension independent of the wire and spool mass;
- Occupy a small amount of space;
- Be reliable and maintenance-free; and
- Cost less than commercially available tensioners;

Based upon the preceding tension system requirements, two tensioning techniques were considered. One technique consisted of passing all 90 warp wires through a channel containing a high velocity air stream, as shown in Figure 1. The viscous drag of the air on the outer surface of each wire would provide the necessary tension and also provide slack take-up during changing of the shed. The second technique consisted of using 90 friction brakes, each incorporating the wire spool and a slack take-up spring (Figure 2). A prototype of each tensioner was designed, fabricated, and evaluated.

Figure 1. Pneumatic Tensioner

Figure 2. Frictional Tensioner

Although engineering calculations indicated that the required wire tension could be produced by using reasonable air flow rates and velocities, it was found that air turbulence within the channel of the pneumatic tensioner caused whipping and tangling of the wires. Although it is possible that the turbulence problem might have been eliminated by providing individual channels for each wire, this approach was not pursued.

The frictional tensioner showed the greater promise of the two tensioning techniques during initial evaluation and, therefore, received greater development. As shown in Figure 2, wire tension is produced by the weight of the bar pivoting about Point C and contacting the wire on the spool with a felt pad at Point A. Neglecting bearing friction and inertial forces, the tension on the wire being pulled tangentially from the spool is merely a function of bar weight and the coefficient of friction of the felt pad on the magnet wire. The pulley at Point B is attached to a cantilever spring which takes up wire slack during the changing of the shed. The pulley pivoted at Point C allows wire to be pulled at any of several angles with respect to horizontal, without changing the tensioner's static and dynamic response. This provides additional versatility in the design of the creel required to hold the 90 tensioners.

In comparing the frictional tensioner to the previously mentioned requirements for the production tensioning system, the following observations were made.

- Requirement: Provide tension on each wire in the range of 0.1 to 0.5 pound-force (0.445 to 2.22 N).

Comments: The prototype frictional tensioner was connected to the Fletcher Power Fab Loom and operated several hours at 95 picks per minute. At various times, the wire tension was measured and found to vary in a repeatable manner by increasing from approximately 0.1 to 0.5 pound-force (0.445 to 2.22 N), then returning to approximately 0.1 pound-force, as shown in Figure 3. Although this appears to be a relatively large variation in wire tension, it is less than the variations (zero to 0.77 pound-force) (zero to 3.43 N) measured on the Bendix creel utilizing magnetic hysteresis brakes. The variations in wire tension produced by the frictional tensioner are a result of the difference between the static and the dynamic coefficient of friction between the felt pads and the magnet wire.

- Requirement: Tension each wire independently.

Comments: Experience with weaving magnet wire has indicated that independent tensioning of each warp wire is preferable to gang tensioning to prevent excessive elongation of a portion of the warp wires. Because independent

Figure 3. Wire Tension Variations as a Function of Time

tensioning of the warp wires is more expensive than gang tensioning it is not normally done in the weaving industry. The frictional tensioner was designed with a minimum of parts to keep costs low, while providing the necessary individual tensioning.

- Requirement: Make the tension independent of spool size.

Comments: Magnet wire is normally supplied by the manufacturer on one of two spool sizes. The smaller spool has a 2.8-inch flange diameter (71.1 mm) and holds approximately 2 pounds (0.91 kg) of wire. The larger spool has a 5-inch flange diameter (127.0 mm) and holds approximately 4 pounds (1.82 kg) of magnet wire. Because all production sources of magnet wire may not be capable of providing wire on spools of the same size, it is necessary that the production tensioning system accommodate either spool size without affecting wire tension. The frictional tensioner provides essentially constant tension regardless of spool diameter, provided the pivoted weight bar remains approximately horizontal. Therefore, this tensioner will accommodate either spool size by moving the location center of the spool vertically with respect to the weight bar approximately 1 inch (2.54 cm). This feature can be easily built into the creel fabricated to hold the tensioners.

- Requirement: Eliminate the need to adjust tension setting to compensate for wire consumption.

Comments: The tensioning system presently being used by Bendix utilizes magnetic hysteresis brakes to tension each spool of wire. Because each spool of wire is mounted on the shaft of a hysteresis brake, the amount of wire contained on the spool affects both the static and dynamic tension. Therefore, adjustments of the tensioners must be made to compensate for wire usage. As previously indicated, the frictional tensioner is self-compensating and requires no adjustments as wire is consumed.

- Requirement: Make the dynamic tension independent of the wire and spool mass.

Comments: When the tensioning system uses magnetic hysteresis brakes to support and tension each wire, the mass of the wire and spool must be accelerated and decelerated each time the shed of the loom changes. These acceleration forces must be carried by the wire passing from the spool to the loom, and the forces increase with increasing loom speed. It is, therefore, desirable to make the warp-wire tension independent of the mass of the wire and spool.

The new tensioner design provides a light-weight pulley mounted on a cantilever spring to control the dynamic tension. When the shed of the loom changes, the wire must accelerate only the small mass of the pulley and spring rather than the entire spool of wire. Thus, the increase in wire tension due to acceleration forces is reduced considerably and made to be independent of the wire and spool mass.

- Requirement: Occupy a small amount of space.

Comments: The new frictional tensioner occupies more space than either the hysteresis brakes or the gang tensioning equipment. However, preliminary design layouts of a 90-spool creel indicate that a space 10 feet long (3.05 m) by 2 feet wide (0.61 m) by 7 feet high (2.14 m) would be required behind the loom. This is not considered to be an unreasonable amount of space. Therefore, the new tensioner design is adequately compact.

- Requirement: Be reliable and relatively maintenance-free.

Comments: The two pulleys required for each tensioner are to be fabricated from an acetal resin polymer such as Delrin[®] AF, manufactured by DuPont, which has high natural lubricity and good wear characteristics. These pulleys should provide a long life with no need for lubrication. The flexural life of the cantilever springs could cause difficulty because they must flex approximately 1.2 million cycles for each 100 hours of loom operation. These springs will be evaluated further to assure that the stresses caused by bending are sufficiently low to assure reasonably long spring life.

- Requirement: Cost less than commercially-available tensioners.

Comments: Although precise cost estimates have not been obtained for the new frictional tensioner, it is estimated that the cost should be less than 20 dollars per tensioner in quantities of 100. This compares favorably to approximately 60 dollars for the hysteresis brakes and 30 dollars each for a more complicated commercially-available frictional tensioner.

Of the tensioner characteristics discussed above, it was considered that the problem of tension fluctuations, as illustrated in Figure 3, required further attention. However, it was also decided that the tensioner design should not be changed in a way that would eliminate the other desirable characteristics of the design shown in Figure 2. The tensioner was thus redesigned (Figure 4) to reduce the range of fluctuation of wire tension. The redesign merely consists of mounting the cantilever spring upon the pivoted weight bar rather than upon a separate support. This provides a feedback mechanism which reduces

Figure 4. Frictional Tensioner With Feedback

the force on the felt pad as wire tension increases, and increases the force as wire tension decreases. An analysis of the effectiveness of this modification in reducing fluctuations in wire tension follows. The wire tension produced by the tensioner without feedback, as shown in Figure 2, may be calculated by performing torque balances about pivot Point C and the wire spool center.

W = weight of bar in pounds (kg).

L_1 = distance in inches (m) from Point C to the center of gravity of the weight bar.

L_2 = distance in inches (m) from pivot Point C to Point A where the felt pad contacts the wire on the spool.

r = radius in inches (m) to outermost layer of wire on spool.

T_s = static wire tension, in pound-force (N).

T_m = dynamic wire tension, in pound-force (N).

μ_s = static coefficient of friction between felt pad and wire.

μ_m = dynamic coefficient of friction between felt pad and wire.

F = normal force in pounds (N) on wire at Point A.

$$\begin{aligned} T_s r &= \mu_s F r \\ T_s &= \mu_s F \end{aligned} \tag{1}$$

$$\begin{aligned} T_m r &= \mu_m F r \\ T_m &= \mu_m F \end{aligned} \tag{2}$$

$$\begin{aligned} FL_2 &= WL_1 \\ F &= \frac{WL_1}{L_2} \end{aligned} \tag{3}$$

Substituting Equation 3 into Equations 1 and 2,

$$T_s = \frac{\mu_s WL_1}{L_2}$$

$$T_m = \frac{\mu_m WL_1}{L_2}$$

Solving for the ratio of static to dynamic wire tension,

$$\frac{T_s}{T_m} = \frac{\frac{\mu_s WL_1}{L_2}}{\frac{\mu_m WL_1}{L_2}} = \frac{\mu_s}{\mu_m} \quad (4)$$

By similar torque balance, the wire tension using feedback, as illustrated in Figure 4, may be calculated as in Equation 5.

L_3 = vertical distance in inches (m) from pivot Point C to wire exiting from the bottom of the spool.

$$FL_2 = WL_1 - TL_3$$

$$T_s = \mu_s F$$

$$FL_2 = WL_1 - \mu_s FL_3$$

$$F(L_2 + \mu_s L_3) = WL_1$$

$$F = \frac{WL_1}{L_2 + \mu_s L_3} \quad (5)$$

Substituting Equation 5 into Equation 1,

$$T_s = \mu_s F = \frac{\mu_s WL_1}{L_2 + \mu_s L_3} \quad .$$

Similarly,

$$T_m = \mu_m F = \frac{\mu_m WL_1}{L_2 + \mu_m L_3} \quad .$$

Solving for the ratio of static to dynamic wire tension, and assuming $L_2 \cong L_3$,

$$\frac{T_s}{T_m} = \frac{\frac{\mu_s WL_1}{L_2 + \mu_s L_3}}{\frac{\mu_m WL_1}{L_2 + \mu_m L_3}}$$

$$\frac{T_s}{T_m} \cong \frac{\mu_s}{\mu_m} \left(\frac{1 + \mu_m}{1 + \mu_s} \right). \quad (6)$$

Using Equations 4 and 6, and the following assumptions, the ratio of static to dynamic wire tension (for the tensioner with and without feedback), may be calculated and plotted as a function of the ratio of static to dynamic coefficients of friction, as illustrated in Figure 5.

Assumptions

- The static coefficient of friction is always greater than the dynamic coefficient of friction.
- The dynamic coefficient of friction is 0.1. This assumption is based upon empirical data taken from the evaluation of the prototype tensioner.

As shown in Figure 5, the feedback mechanism significantly reduces the fluctuations in wire tension caused by the differences in the static and dynamic coefficients of friction between the felt pad and the wire. Although the tension fluctuations are not eliminated, the fluctuations are reduced to an acceptable level.

Figure 5. Ratio of Static to Dynamic Wire Tension Versus Ratio of Static to Dynamic Coefficients of Friction

ACCOMPLISHMENTS

A frictional tensioner, which incorporates tension feedback, was designed and is expected to provide reliable control of the warp-wire tension during the weaving process.

FUTURE WORK

Creels, incorporating 90 of the frictional tensioners, will be fabricated and subjected to prove-in at Bendix Kansas City. If successful, the creels are to be evaluated in conjunction with vendor looms for weaving wire tape. This wire tape is to be thoroughly inspected and subjected to anticipated process environments by fabricating simulated production units. A Sandia Laboratory specification will be used to thermally-cycle and to check electrically the simulated production units to assure that the weaving process did not adversely affect the insulated wires within the woven tape.

Appendix A

DEFINITION OF WEAVING TERMS

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DEFINITION OF WEAVING TERMS

Beat Up	The action of the reed that drives the fill yarn against the woven fabric.
Bobbin	Spool which carries the fill material in the shuttle.
Count	Number of warp yarns per inch or number of fill yarns per inch.
Creel	Frame which holds spools of warp fibers (or wire).
Dent	Open space in reed.
Fabric, Woven Narrow	A fabric less than 12 inches (0.305 m) in width with a selvage on each side.
Fill	The wire running crosswise in the fabric (perpendicular to the selvage).
Heddle	A series of vertical cords or wires that raise and lower the warp to form the shed.
Pick	An individual fill yarn.
Pick Count	The number of fill yarns per inch of fabric.
Reed	The part of a loom consisting of numerous thin parallel vertical strips that drives the fill yarn against the woven fabric.
Resort Spring	Spring, contained in the shuttle, which maintains tension on the fill material.
Selvage	The woven edge portion of a fabric parallel to the warp.
Shed	The opening produced by separating the warp wires vertically to allow passage of the shuttle.

Shuttle	The device used to carry the fill yarn to and fro between the warp.
Slay	The portion of the loom, to which the reed is mounted, that moves forward to beat up the fill material.
Tape	A narrow woven fabric with a maximum width of 8 inches (0.203 m).
Warp	The yarn running lengthwise in a woven fabric.
Weave, Plain	A fabric pattern in which each yarn of the fill passes alternately over and under a yarn of warp and each yarn of warp passes alternately over and under a yarn of the filling.
Weft	Fibers perpendicular to warp; also known as woof, or fill.
Woof	Fibers perpendicular to warp; also known as weft, or fill.