WIRE STRETCHING MACHINE FOR SPARK CHAMBERS

H. Alleyn, J.J. Guezennece and G. Muratori
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1. **INTRODUCTION**

This machine was built as a prototype in 1966, following requests from a few experimental teams for very large wire spark chambers.

At that time, the largest chambers of which we had some experience were about \( 1 \times 1 \) m in size. We decided to build a wire-stretching machine that could cover a surface of about \( 4 \times 5 \) m; however, owing to the large area of floor-space taken up by such a machine, and to the demand for the largest sizes being still in the realm of future possibilities, the prototype was built around a smaller frame, originally \( 1.60 \times 1.20 \) m, subsequently broadened to \( 2.20 \times 2.40 \) m, and recently to \( 3.50 \times 3.60 \) m.

The size of the machine may be changed without difficulty because the components are mounted on a main beam made of an anticorodal tube, and it takes only a moderate amount of work to rearrange them on a longer or shorter tube.

This tubular beam (which may be seen in Fig. 1) carries a chariot, together with its driving mechanism, two advance escapements, and a servo-mechanism that supplies the wire to be stretched, keeping it under constant tension.

The main beam is supported, near both ends, by wheels that travel over two racks between which the wire is stretched. These racks are mounted on a frame that keeps them at a constant distance.

![Fig. 1](image)

General view of the machine
When the machine is working, the chariot travels along the main beam, laying down the wire from one rack to the other. At the end of each stroke the main beam advances a small distance along the racks, thereby accomplishing the function of feeding the wire into the proper position. Thus it may be said that the travelling chariot performs the working motion and, being mounted on the main beam, also the feeding motion, whilst the work (i.e. the plane of wires laid down in succession) remains stationary all the time. This is one way in which our machine is different from a textile loom, where the cloth moves as it is produced whilst the machinery remains at the same place. But the most important difference is that a loom has both a longitudinal and a transverse system of threads, or a warp and a weft, whilst the stretching machine has only the weft, all the wires being parallel and without interlacing.

The latter feature allows a remarkable simplification in the position of the wire-reserve spool because, instead of being inside a shuttle, the spool may be mounted on the main beam, from which the wire is taken to the travelling chariot through idler pulleys.

We may conclude that the wire-stretching machine, having only some of the features of a loom, has a much simpler operating principle. During the construction, most difficulties were technical ones; in particular, much care was necessary when handling the thin metal wires and controlling their tension. Also, the means by which the pitch of the wires was kept within close tolerances required some consideration. But let us study the different parts in detail.

2. MAIN BEAM AND CHARIOT

The main beam consists of an aluminium alloy (anticorodal) tube that takes the compressional stresses corresponding to the resultant of the tensions of three 10 mm diameter centreless ground-steel bars, mounted between two plates fixed at the ends of the tube (Fig. 2).
Two of these bars are used as rails for the chariot, which is guided on the lower one by five ball-bearings and on the upper one by two, so that the only remaining degree of freedom is a translation along the beam. On the lower bar, four bearings are mounted symmetrically on the upper side, whilst the fifth one is opposite and in the middle of the span covered by the upper bearings; the length of the intermediate span is sufficient to give the bar some flexibility and, by suitable adjustment of the lower bearing, this elasticity may be used to pre-load the bearings and suppress the play.

The chariot carries three small pulleys that keep the wire in the correct plane, and two plunging needles that perform the operation of releasing and hooking up the wire at the end and at the beginning of each stroke, respectively. In addition to these parts, the chariot carries a clamp for securing a nylon driving-string and a bar that operates two microswitches at the end of each stroke. These switches are mounted towards the extremities of the main beam, and are used to reverse the direction of the drive and to advance the beam. When approaching the end of a stroke, the chariot comes under a linear cam, also fixed near the end of the main beam, that operates the plunging needles through a roller cam-follower.

The chariot driving system is mounted on the end-plate at one side of the main beam, and consists of a 100 W motor driving a nylon string by means of a reduction gear and a capstan. The string, made of 2 mm diameter solid nylon, starts from the chariot and goes around the capstan, and then to a return pulley on the opposite end of the beam, from which it comes back to the chariot.

The motor used for the drive is a commutator, series-wound, a.c. motor, which has a torque characteristic suitable for this type of operation. The speed may be adjusted to different working conditions by means of a variable transformer.

The wheels that carry the main beam, so that it may travel along the supporting racks, are mounted on two chariots fixed near the ends of the beam. These chariots also contain the feed or advance mechanism, which consists of an anchor escapement driven by a coil.

3. WIRE DELIVERY UNIT

The wire delivery unit is mounted at approximately the centre of the main beam. This unit consists (Fig. 3) of: a 50 W a.c. two-phase servo-motor driven by an external amplifier; a control transformer giving the wire tension error signal; and a tachometer generator giving a damping signal proportional to the rate of change of the wire tension. The error detection is obtained by comparing, on the same shaft, the torque due to the tension of the wire with a reference torque that may be set at different values by adjusting the tension of a spring. The error signal, to which is added the damping signal, is amplified and fed back to the motor; this, in turn, controls the wire-reserve spool by means of a suitable transmission ratio, and delivers or recovers wire according to whether the wire tension is increasing or decreasing. Therefore the servo-mechanism behaves as a spring of infinite length, and may be presented as a device for keeping the tension of the wire at a constant set value, or as a source that continuously delivers as much wire on one side of the measuring arm as is taken away by the chariot on the other side, thus keeping the arm in a fixed position, i.e. the wire at constant tension. The two ways are strictly equivalent, the change in tension being proportional to the difference of the outgoing and incoming lengths of wire through the elasticity constant of the spring, and through the arm ratio between the point of application of the spring and the centre of the pulley (Fig. 4).
Fig. 3
Wire delivery unit

Fig. 4
Schematic layout of servo-mechanism
4. **WIRE SUPPORTING FRAME**

The wires are stretched between racks bolted to the longitudinal girders of a rectangular frame made of tubular steel. The frame is stiffened by transverse bars that support lighter anticorodal flat bars which have vertical slots; these bars may be raised or lowered in order to adjust spark chamber frames to the proper height for bringing them into contact with the wires when the latter are being transferred from the machine to the spark chamber frames. The transfer is done either by gluing or soldering, and the tension is always maintained.

A few words should be said about the racks, since they perform more than one function: apart from supporting the main beam and providing a fixing point for the wires, they also define the pitch of the wires and the step by step advance of the machine. The racks are not milled, as this would be a long and difficult operation, particularly in view of the undercut profile of the teeth as shown in Fig. 5. The machining is done on a lathe, four rack elements of 1.2 m in length being mounted along a bar that has a cross-shaped section. The racks are thus threaded in the same way as a screw, the inclination of the helix being negligible because of the fairly large turning diameter. After cutting, each tooth is individually rounded at the external edge about which the wire turns (Fig. 6). The rounded surface is machined at an angle with respect to the height of the tooth, so that the wire may not slide off easily. This operation is still done by hand on a small home-made machine that guides the tool at the proper angle and advances the rack by means of a screw whose thread is in mesh with the rack (Fig. 7). The wire-supporting frame is mounted in an inclined position, and the main beam advances along the rack by gravity, one tooth at a time, controlled by the escapements.

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Fig. 5
Needle and teeth

Fig. 6
Wire layout
5. **ESCAPEMENTS**

As mentioned previously, the escapements are mounted on the two chariots near both ends of the main beam. They are of the anchor type, with an elastic entering pallet and a rigid exit one (Fig. 8). At each stroke the entering pallet slides slightly on its support when butting against a tooth, and comes back to the original position when going out. This is to take into account the fact that, contrary to the teeth of a clock escape-wheel, those of the racks must be thick. Indeed, they occupy something more than half of the pitch, and a rigid escapement would require teeth of negative length.
The escapements are operated alternately: for a given wire pitch, the main beam advances by twice that pitch on the side where the travelling chariot is reaching the end of the beam. When the chariot goes back to the other end, the beam advances on this side by the same amount. Thus the beam is never exactly square with respect to the frame but takes alternate symmetrical positions and advances of the correct average pitch, although not simultaneously on both sides. As a result, the wire is laid down following a zig-zag path, as shown in the successive positions of Fig. 6.

6. OPERATION OF THE NEEDLES

The needles, which are carried by vertical plungers fixed to the chariot, travel for most of the stroke in their upper position. When approaching the ends (Fig. 2) they are pushed down by the cam, except for the very short fraction of stroke that corresponds to the passage of the rack. Here the needle has to be raised in order to clear the rack and therefore the cam has a notch in this region. The trailing needle that carries the wire goes first down, and then up, and finally down again but with no effect because the wire continues to slide on the smooth and rounded groove on the upper part of the needle.

When the chariot reaches the furthest point beyond the rack and operates the microswitch, the main beam advances by one step and the wire comes into contact with the undercut part of the tooth of the corresponding rack; the chariot goes back, and the wire, which is kept in a plane at approximately 20° with respect to the racks by the last two idler pulleys, leaves the needle, winds itself around the tooth, and goes back. The needle and pulley that were leading now become trailing, and the wire gradually comes back to a direction near to the one of motion. At this stage the now trailing needle, having been raised to clear the rack, comes down again immediately after and, sliding along the wire, hooks up the wire in the wire-guiding groove. In order to catch the wire, the needle must come down very rapidly before reaching the mobile crossing-point P (Fig. 9); therefore the cam is rather steep in this region.

It should be remarked that the plungers make several up and down strokes, only a few of which are actually used; this does not cause any inconvenience, and it was thought to be a simpler solution than others that would have been more economical only in motion intensity.

7. CONTROL PANEL

The control panel contains three units, namely: a variable transformer for controlling the motor that drives the chariot; a servo-amplifier with adjustable and separate gain controls for the error and damping signals; and a power supply for the amplifier. It is
connected by a flexible cable to one end of the main beam, all the other wiring being made by cables that run inside the beam. The circuits are classical for this type of operation, and a detailed description does not seem to be necessary. Their design has been very much influenced by time considerations and by the available electronic components. Although the circuits have been working regularly since the machine was built, they could now be improved by the use of better components and by devoting more time to their study.

It may still be mentioned that the circuits embody two safety interlocks that stop the machine when the wire is broken and when the wire is not regularly attached to the rack. In this case, during the return stroke the servo-mechanism takes back not only the length of wire corresponding to the distance travelled by the chariot beyond the rack, but also the length of wire laid down during the previous stroke. Consequently, the spool makes several turns backwards, and a spiral mounted on its shaft drives an arm against a monitoring microswitch. The motion is very similar to the one that the pick-up arm of a record-player would have if, at the end of the play, the record would start to turn backwards.

8. PERFORMANCES

The machine is capable of stretching wires of 0.03 to 0.2 mm in diameter, under tensions ranging between 20 and 500 grams. The average travelling speed along the stroke is about 0.5 m/sec. As may be seen from the layout, the servo-mechanism stays almost idle during the first half of each stroke, and has to deliver the wire at about twice the speed of the chariot during the second half. The switching over from one condition to the other must be gradual and, to achieve this effect, the idler pulley that delivers the wire to the chariot is mounted appreciably higher than the receiving pulley on the chariot.

Before deciding on a servo-mechanism, other, more simple, solutions were tried, such as the one of applying a tension to the wire by means of a motor compelled to turn against the sense of rotation for which it was energized. However, these solutions had to be discarded as unsatisfactory, with respect to the required fast response at the end of the stroke, and to the impossibility of keeping the tension constant when the delivery speed is changing, as seen above. With the servo-mechanism, the speed limit of the machine is set by the maximum flat-top delivery speed during the second half of each stroke, rather than by the frequency response at the ends.

9. DEVELOPMENT WORK

The machine has been used intensively, and we decided to build a few more in order to satisfy all the requests and to cover more economically the different sizes of spark chambers. In the new models the improvements have been mostly technological, so that the machines may be less expensive to produce, and easier to adjust and to use. Some consideration has been given to the reduction of inertia and of friction, particularly where this may affect the tension regulation. The main advantage should be the possibility of working with thinner wires and gaining something on the speed.

Other developments may be in the direction of reducing the wire spacing or of covering ruled surfaces of different geometrical shapes, e.g. cylinders or hyperboloids.
10. WIRES

The wires most commonly used are beryllium-copper and phosphor-bronze of 0.1 and 0.07 mm in diameter. Beryllium-copper is higher than bronze in ultimate tensile strength, but more expensive and fragile when turning around a sharp corner. Other materials have been used, such as piano-wire steel, stainless steel, gold-plated molybdenum, etc., as shown in the table.

On a rotating-frame machine built in 1965, F. Kriemen used a device where the wire comes out crinkled after passing through two small gears, whose distance may be adjusted. Wires thus formed have a greater elongation for a given applied stress, and they behave, although not linearly, as if their modulus of elasticity had been reduced. These wires are less affected than are plain wires by the flexibility of the spark chamber frames, and this is an important advantage when the spark chamber sides have to be kept relatively light.

On account of these characteristics, the same device was embodied in the machine.

Once the wires have been stretched, their pitch is very regular as an average, but it may have local defects. For instance, stiff wires of the largest diameters tend to stay open where they turn around the teeth of the rack, and give a pattern with an alternation of a long and a short pitch. To bring the wires into the proper place, combs are normally used. These combs are produced, like the racks, by turning, eight of them being machined on the same bar and cut at an angle of about 45°.

Changes in the pitch of the wires cannot be effected easily on a given frame, except if they are multiples of the basic pitch. However, the machine may be transferred onto a frame of a different pitch. If the new pitch is a submultiple of the distance between the escapement pallets, no adjustment should be required.

The wires are usually fixed on the spark chamber frames by gluing with epoxy resin or by soft soldering. In the latter case, the frames carry a printed circuit having a pitch as equal as possible to the pitch of the machine.

Soldering is done by driving, on a rail, a chariot carrying a soldering iron that deposits the tin successively on the contact between the wires and the lines of the printed circuit. This procedure is still manual, and depends on the skill of the operator and on the accuracy of the circuits, the frame length soldered per hour being between 1 and 4 m according to the circumstances.

Acknowledgments

We are grateful to Prof. P. Preiswerk for constant encouragement in our work. We would like to thank Messrs. R. Benoit, H. Bertrand, F.H. Doughty and G. Gendre, who participated in the development and construction of the prototype; Dr. A. Susini for his suggestions and discussions of the performances of the servo-mechanism; members of the MSC-NP Drawing Office and of the West Workshop for development work on the new machines; and a number of colleagues whom we do not mention personally but to whom we feel grateful for their participation.
### Physical properties for wires of different materials

<table>
<thead>
<tr>
<th>Material Description</th>
<th>A: annealed</th>
<th>H: hard-drawn</th>
<th>T: thermo, treated</th>
<th>Ultimate tensile strength (kg/mm²)</th>
<th>Elongation (%)</th>
<th>Yield strength (kg/mm²)</th>
<th>Modulus of elasticity (GPa)</th>
<th>Density (g/cm³)</th>
<th>Resistivity at 20°C (μΩ·cm)</th>
<th>Specific heat at 20°C (cal/°C·g)</th>
<th>Thermal conductivity at 20°C (W/m·K)</th>
<th>Melting temperature (°C)</th>
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<tr>
<td>Copper (99.9% pure)</td>
<td>A</td>
<td></td>
<td></td>
<td>21</td>
<td>35</td>
<td>4</td>
<td>13,700</td>
<td>8.90</td>
<td>1.73</td>
<td>0.918</td>
<td>0.092</td>
<td>1083</td>
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<tr>
<td></td>
<td>H</td>
<td></td>
<td></td>
<td>38-48</td>
<td>2-4</td>
<td>34-45</td>
<td>12,500</td>
<td>9.00</td>
<td>1.79</td>
<td>0.930</td>
<td>0.092</td>
<td></td>
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<td>Phosphor-bronze (5% 1.5-3.5)</td>
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<td></td>
<td></td>
<td>25-90</td>
<td>1-0.5</td>
<td>13,500</td>
<td>8.87</td>
<td>5-10</td>
<td>0.50</td>
<td>0.16-0.32</td>
<td>0.092</td>
<td>1000</td>
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<td>Deryllium-copper (Be 25%)</td>
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<td></td>
<td></td>
<td>110-130</td>
<td>2-1</td>
<td>90-105</td>
<td>13,000</td>
<td>8.25</td>
<td>5.7-7.8</td>
<td>0.28</td>
<td>0.10</td>
<td>970</td>
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<td></td>
<td>H</td>
<td></td>
<td></td>
<td>75-200</td>
<td>35-2</td>
<td>40-150</td>
<td>80-100</td>
<td>8.00</td>
<td>80-100</td>
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<td>Molybdenum a)</td>
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<td></td>
<td></td>
<td>160-180</td>
<td>5-3</td>
<td>100-150</td>
<td>33,000</td>
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<td></td>
<td>150-160</td>
<td>5</td>
<td>105-115</td>
<td>21,000</td>
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<td>8.8</td>
<td>9.5</td>
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<td>95-115</td>
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<td></td>
<td>42-45</td>
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<td>20</td>
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<td>H</td>
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<td>70-75</td>
<td>3-2</td>
<td>55-60</td>
<td>17,500</td>
<td>8.9</td>
<td>49</td>
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<td>H</td>
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<td>140</td>
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<td></td>
<td></td>
<td>140</td>
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<td>0.032</td>
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<td>Al-6Si-0.5Mg (0.5%)</td>
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<td></td>
<td></td>
<td>30-35</td>
<td>9-6</td>
<td>27-31</td>
<td>6,700</td>
<td>2.7</td>
<td>3.25</td>
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<td>600</td>
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<td>1.77</td>
<td>1.77</td>
<td>0.98</td>
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a) also available gold-plated  
b) also available copper-plated.