CLOCK LINES – 1

Stranded steel and brass/bronze lines

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The clock line is a pretty unexciting if essential component, and the benefits or otherwise of the standard types of line are somewhat clouded with advertiser's puffery and opinion seemingly lacking substantiation. This paper considers stranded steel, brass/bronze, natural gut and monofilament synthetic lines. Ropes and braided lines are not considered, nor are those made of more recent materials such as aramid or carbon fibre. The arrangements considered are shown in Figure 1.

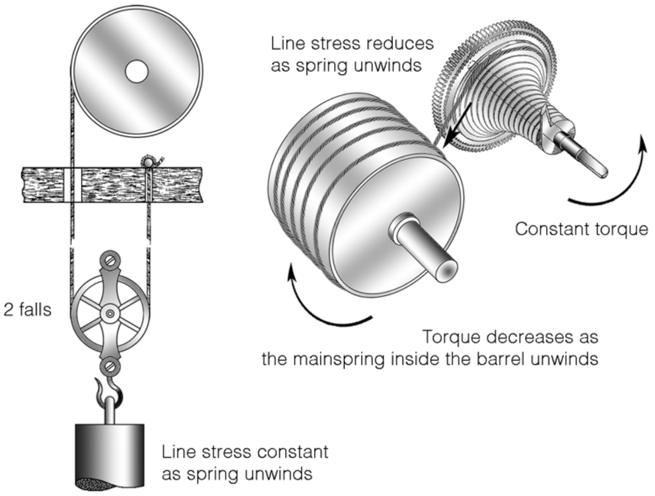

Figure 1: Typical use of lines in a weight-driven and spring-driven fusee clock

Primary requirements

The primary requirements of a clock line can be stated in a few bullet points:

- The materials should be suitable for the environmental conditions in which the clock works,
- Its tensile strength should comfortably carry the load for the desired life,
- It should be flexible enough to pass freely over a pulley or the small end of a fusee,
- It should not creep to an extent that may compromise the performance of the clock.

In practise, horological requisites catalogues leave most of these requirements unquantified, and even the type and quality of material is frequently left somewhat vague. Today there is little doubt in the writer's view that, of the types this paper considers, stranded steel is by far the best choice and, had it been available, would have been the choice for fusee instruments rather than the link chains with which they were fitted.

Stranded steel and brass lines

Horological requisites suppliers generally supply 7 x 7 stranded line, but brass lines can sometimes be supplied as 1 x 19 or even 1 x 7. The latter should be rejected; essentially it is picture cord, and brass having a poor fatigue (cyclic bending) life in its hard-drawn state is totally unsuited to continual flexing. 7 x 19 is undoubtedly the most flexible and is available in stainless steel from wire rope and line suppliers – Figure 2.

Steel and brass (or bronze – the difference is not that significant for clock lines) lines need to be stranded to give them flexibility to wrap around the drum, pulley and/or fusee, and the greater the number of wires the more flexible the line – Table 1. On a fusee clock, the line will have to bend around the small end of the fusee, which may well be quite a small diameter that is lower than the recommended minimum in Table 1. Experience has shown that diameter down to 50% of the tabulated diameters will be satisfactory for the expected number of lifetime fatigue cycles.

The 'lay' can also vary, but for horological purposes 'normal lay' in which the strands are wound in one helix direction and the wires in the opposite direction is perfectly satisfactory.

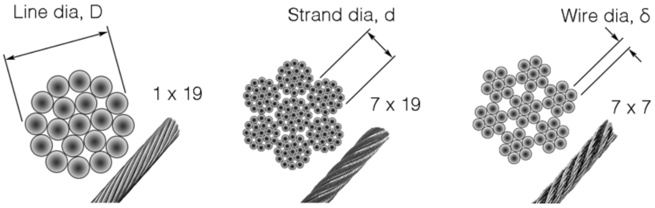

Figure 2: Typical stranded wire lines

Material	Construction	Line dia.	Typical swl	Minimum pulley dia.	Bending flexibility
Steel or stainless steel	7 x 19	1.5 mm	26 kg	27 mm	Extra flexible
	7 x 7	1.5 mm	30 kg	42 mm	Flexible
	1 x 19	1.5 mm	38 kg	Unsuitable	Stiff
	7 x 7 nylon coated	1.0 mm (1.5 mm od)	15 kg	32 mm	Flexible
Brass or bronze (inferred)	7 x 7	1.0 mm	12 kg	60 mm	Flexible
	7 x 7	1.4 mm	25 kg	84 mm	Stiff
	1 x 7	1.5 mm	-	Unsuitable	Very stiff

Table 1: Recommendations based on suppliers' data for the maximum curvature of stranded lines. Annexe A and B give an insight into the derivation of the tabulated figures

Line strength

In engineering, a stranded (steel) line invariably has a maximum safe working load (SWL) specified, which generally incorporates a factor of safety of around 5. When compared to a solid wire of overall diameter *D*, stranding a wire reduces the cross-sectional area capable of taking load, though this is largely offset by the higher tensile strength of finely-drawn thin wires.

The perhaps slightly pessimistic line loads in a typical 2-fall longcase clock are of the order of 35 N (3.5 kg) and, for an English fusee clock, perhaps a maximum of 100 N (10 kg), this latter figure being calculated from the measured fusee torque of a clock in the writer's workshop. All stranded steel and brass/bronze lines down to 1.0 mm diameter line will theoretically carry these loads, but, as will be mentioned shortly, line tensile strength is not the only consideration.

The high engineering factor of safety allows for kinking of the rope and general mistreatment in harsh working environments. While it might not seem that a clock line will receive harsh treatment, it can do so when the clock runs down, the line being sharply bent through 90° where it enters the fusee or barrel knot-hole, and elasto-plastic bending will occur every time the owner goes on holiday or forgets to wind the clock – Figure 3. If one assumes a line design life of, say, 20 years, and the owner forgets to wind the clock a pessimistic 10 times a year, this means the elasto-plastic bending could occur up to 200 times. From the writer's experience this elasto-plastic bending will cause fracture well before this time in a stranded brass/bronze line. As an analogy, a paper clip sharply bent back and forth would fracture well before 200 stress reversals.

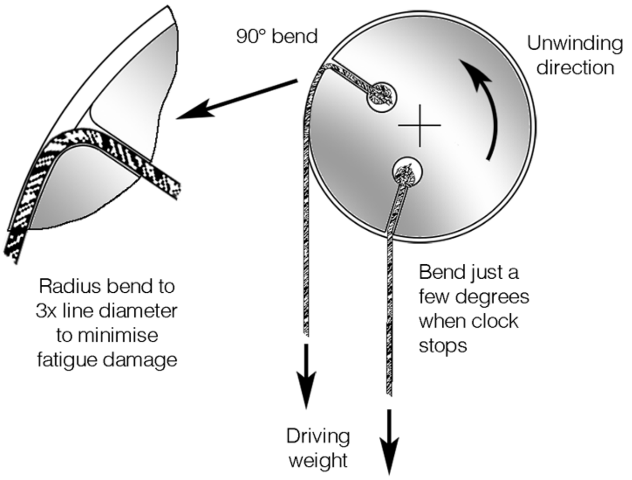

Figure 3: The most likely site of fatigue damage is when the line is cycle through a 90º bend. Also on fusee clocks

This scenario was experienced by the writer, a 7 x 7 bronze line fracturing at the 90º bend after just a few years' service. This could be prevented if the clock were fitted with 'down-stopwork' but in practise clocks with lines never are, the only type satisfying this need is the wall-mounted weight-driven clock where the weight comes to rest on the bottom of the case before the line is fully unwound. Consequently, owners should be advised to stop a clock if likely to be away from the clock for more than the going period (ie. be unable to prevent the clock from fully unwinding).

For this reason brass/bronze lines are not recommended, and should never be used if down-stopwork is not fitted. Furthermore, spring-driven fusee lines are generally under higher stress than weight-driven clock lines, and it is unfortunate the highest line stress (line tension) occurs at the small diameter end of the fusee when the bend radius in normal operation is at its lowest. If visual appearance is important (i.e. a yellow colour is required), brass or bronze-plated steel lines should be used.

Line creep

Line creep is not an issue for steel and bronze lines. Creep can be ignored, though the same cannot be said for natural gut or synthetic lines as will be discussed later on.

Line coatings

In addition to being offered brass or bronze-plated, steel lines are also offered galvanised (zinc coated), but the writer's view is that the zinc coating may result in increased inter-strand friction. If the environment is likely to be corrosive (humid), better would be a 316 austenitic stainless steel line or perhaps nylon coated line. If choosing the latter, one should ensure the coating is nylon and not PVC ('vinyl') as generally stocked by horological requisites suppliers.

Nylon is more resistant to tearing when bent or rubbed, the slightly cheaper vinyl being primarily intended for static wire guardrail applications such as in 'wow-haus' type balconies or stair rails as intermediate guard wires. On fusee clocks, vinyl may not last at all well if constantly rubbing over the stop iron of the up-stopwork and should not be used – Figure 4.

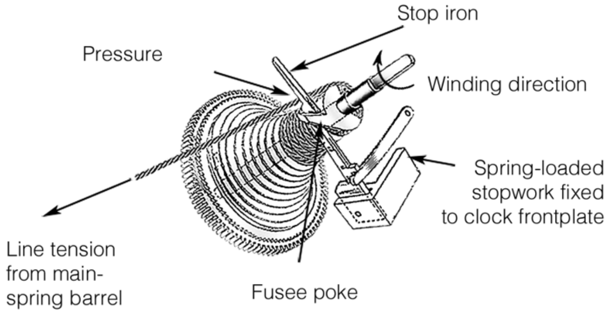

Figure 4: Fusee up-stopwork

In engineering applications, plastic coating of any type is generally not favoured, especially if the coating is opaque (coloured) as it hinders inspection of the condition of the steel strands beneath.

Annexe A. Line bending radius

To give a margin against fatigue damage, the allowable pulley diameter (bend radius) can be based on a percentage of the yield strain – the allowable strain – of the individual wires:

$$PD_{min} = d_{wire}/\varepsilon_a$$

where *PD_{min} = minimum pulley diameter,*
d_{wire} = individual wire diameter, and
ε_a = allowable strain

Less easy to determine is the individual wire diameter, which is not often stated by the suppliers. Nor is the yield strain of the specific wire alloy known to any great accuracy, which makes a more scientific calculation difficult, especially for a fusee line with its load reducing by as much as 60% or even more between fully wound to fully unwound. Yield ignores cyclic (fatigue) loading, which for a weekly wound clock over a 50 year life equates to a relatively modest 5000 stress reversals. One alternative starting point might be the SWL strain, but this does include a factor of safety of 5, though it will effectively embrace fatigue damage.

Typical line stresses in weight-driven and fusee clocks are discussed in Part 2, a broad-brush estimate being 60 MPa maximum for a spring-driven English fusee (bracket) clock and 20 MPa for a weight-driven English longcase clock.

Some suppliers do provide tabulations of the minimum diameter to ensure a (generally unstated) 'long life' if cycled around the pulley at the SWL, and these are the figures appearing in Table 1. Stranded brass/bronze lines not being a recognised engineering material for construction of high-duty lines, these figures were inferred using a degree of 'engineering judgment' by the writer.

Taken together, the writer suggests that diameters perhaps up to half the recommended minimum bending diameters are acceptable, and with the small diameter of fusees invariably being closer to this figure, this is borne out in reality. Nevertheless, the writer is firmly of the opinion that brass or bronze is a largely unsuitable material for line construction.

Perhaps the one exception to the use of brass is the precision 28-day Lanterndluhr or Dachluhr Vienna regulator with its small driving weight, small diameter line (typically 0.8 mm) and low number of stress reversals. However, the energy loss will always be greater with stranded brass than a non-metallic line of similar diameter.

Annexe B. Line bending losses

The writer made a few simple calculations to see what the line bending losses were, which reinforces the view that the more flexible the better if one wants to minimise the driving weight (such as might be the case in a 28-day Vienna regulator).

Assuming 50% energy recovery and the pulley on a 2-fall 8-day longcase clock is the same as the barrel diameter making two full turns per 24 hours, the energy required every day to bend a line round both pulley and barrel can be crudely approximated by the expression:

$$Bending\ energy = \frac{2 \times N \times \pi \times E \times d^4}{6 \times D}$$

where *N = the total number of wires,*
E = the modulus of elasticity,
d = the individual wire diameter, and
D = pulley/barrel diameter.

This suggests that a typical 1.5 mm diameter 7 x 7 stranded steel line wrapped around a 38 mm diameter pulley and barrel absorbs 0.2 joules per day or 1.5 joules per week, which is about one thirtieth of the total available weekly energy from the fall of weight. Change to stranded wire of 7 x 19 construction and the energy falls to just one-third of this level (0.5 joules per week), but change to brass picture cord of 1 x 7 construction and the weekly energy consumption massively increases to 10 joules per week, quite apart from it almost certainly having a short fatigue life from the wire being plastically bent at each winding and unwinding.

Next time: Natural gut and synthetic lines
