A statistical analyser for random waveforms and its application to yarn mass analysis

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The instrument described is designed for use on random waveforms and provides (i) direct measurement of the cumulative frequency distribution of instantaneous values and (ii) a means of specifying the waveform irregularity structure. The instrument has been made in a form specially suited for the analysis of the linear density of textile yarns but it could probably be employed on other waveforms with a large random component.

1. Introduction

Waveforms arise in various fields of physics and their analysis involves both measuring the dispersion of instantaneous values about the mean and a description of the waveform structure. The measurement techniques and problems vary with the field of application. The instrument to be described was developed for the analysis of textile yarn mass variability, although it could probably be employed on other waveforms with a large random component.

Instruments made for analysing the mass variability of yarns generally give a single measure of this property, such as standard deviation or mean deviation. However, it is often much more useful to be able to determine the actual distribution of yarn mass; not only do the distributions encountered have varying degrees of positive skewness but the practical performance of the yarn is greatly influenced by the nature of the tails of the distribution. Usually the distribution of yarn mass is obtained by cutting and weighing short lengths. However, not only is this procedure extremely tedious, but due to errors in measurement of length and to loss of short fibres its accuracy must be much less than the weighing accuracy. For any extended programme of work an electronic device of the type to be described is essential and this instrument provides direct measurement of the cumulative frequency distribution although, of course, the results may be used to calculate the standard deviation.

When the patterns in a waveform are truly periodic they can readily be described by the Fourier components and in a quasi-periodic waveform the periodic components may be picked out by use of autocorrelation coefficients. An instrument to determine these coefficients has been described (Revesz 1954) but its use would involve separate tests from those performed to determine the distribution curve. Moreover, unless the yarn has a periodicity caused by a machine fault the waveform may be largely random and the autocorrelogram will not give any information about the irregularity structure. It would thus seem that the techniques applied to analysis of electrical noise might afford an appropriate means of specifying the nature of the yarn profile.

Rice (1945) has shown that a noise signal containing all frequencies from zero to f_b crosses its mean value (zero) $2f_b/\sqrt{3}$ times per second. This is termed the number of zeros per second and may be used to calculate the temperature of a conductor producing this thermal noise. In the case of a yarn one would desire as few zeros as possible and measuring this property, or one related to it, should provide an added yarn irregularity parameter.

As well as determining the number of times the waveform crosses its mean value it would be useful to know the number of thick or thin portions occurring in a yarn. With a knowledge of both the length and number of these places it would be possible to distinguish between a yarn with a few long thick portions and one with many short thick portions. Similar comparisons could be made for the thin portions. Thick portions influence the appearance of the yarn and thin portions its minimum strength and so a means of measuring both these would be of value in the assessment of yarn quality.

2. A practical device

Any time dependent variable which can be represented by a voltage of suitable amplitude may be analysed by suitable electronic circuits. A typical waveform is shown in figure 1

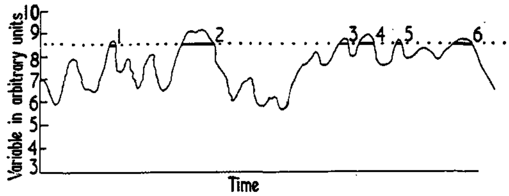

Figure 1. Analysis of a time dependent variable.

and it is desired to examine this waveform at a number of different levels, one of which is shown in the figure. The line is solid wherever it is enclosed by the envelope of the curve but is dashed for the rest of its length. It is desired to measure the total length of the solid portions and to count the number of pieces into which it is broken.

The analyser to perform these two functions for a yarn consists of three main parts: (i) a capacitance bridge and amplifier to convert yarn mass to a voltage signal; (ii) discriminators to switch the counting circuits on and off at the desired preset levels; (iii) the length (time) marker to produce a train of pulses to operate the length distribution counters. These parts are shown with their interconnections in the block schematic diagram of figure 2. The signal from the capacitance bridge amplifier is fed equally to each of the discriminators and when the signal rises above the preset level a discriminator allows the pulses from the length marker to operate the length distribution counter. When the signal falls below a preset level the discriminator switches off its length counter and also causes one count to be recorded on the second counter, which is termed the occurrence counter.

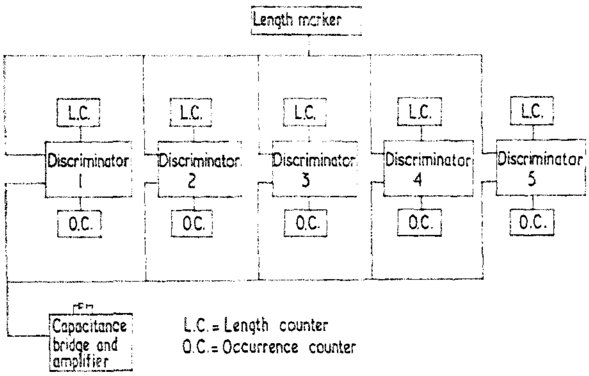

Figure 2. Analyser (schematic diagram).

At the same time the pulses from the length marker are used to control the total length tested.

The three parts are described in greater detail below.

(i) Capacitance bridge and amplifier. The yarn mass is measured by passing it through a parallel plate capacitor connected into one arm of the bridge. The capacitor has one plate surrounded by an earthed guard ring and the whole is rigidly constructed and well screened. The yarn is passed along the horizontal axis of the capacitor but in contact with the unguarded plate and the length of yarn under investigation is defined by the length of the guarded plate. Typically the guarded plate is a 1 in. square and for use with yarns of about 250 to 500 Tex* the spacing of the plates is about 75 thousandths of an inch. With this plate it is the profile of the mass of 1 in. lengths which is examined.

The circuit used is a modified Fielden capacitance comparator, the main modification being the provision of a stabilized d.c. power supply and a capacitance calibration device. In this equipment the bridge is energized by a 200 kc/s oscillator and the out-of-balance current is amplified by a two-stage radio-frequency amplifier. The amplifier output is detected and fed both to an indicating meter and to the input of the discriminator circuit.

As it is desired to relate the output of the capacitance comparator to the linear density of the yarn a calibration capacitance is provided and, in the absence of suitable commercial capacitors, this has been specially constructed. Two cylindrical capacitors 1·75 in. long were made each with an outer electrode diameter of 1 in. and an inner electrode of 0·25 in. B.S.W. screwed rod. The calibration capacitance is obtained by the differential setting of the two central electrodes. A Telephone Manufacturing Company Ltd. low capacitance switch is used to switch either one or other of the calibration capacitors into parallel with the test capacitor.

To overcome non-linearity of the detector stage the zero of mass is off-set to 0·2 mA and the capacitance balance control in the bridge is adjusted to obtain this current when the smaller of the two calibration capacitors is switched in. The larger calibration capacitor is then switched in and the gain control of the amplifier adjusted to give an output of 1 mA. Successive adjustment is made of the balance and gain controls until the 0·2 and 1·0 mA readings are obtained for the appropriate calibration capacitors.

The output fed to the discriminator stage is obtained by using a separate germanium diode coupled directly to the anode of the second radio-frequency stage which gives an output variable from 8 to 36·0 V for the range 0·2–1·0 mA on the indicating meter.

(ii) The discriminators. The counters must be switched on and off at predetermined voltage levels and the circuit for this is shown in figure 3. The cathode follower feeds five discriminators through the five potentiometers in parallel in its cathode load. Each discriminator is followed by a triode connected pentode driving a Siemens Halske Type Trls 154c high speed relay.

The attenuators are 30 kΩ 10 turn helical potentiometers in series with a 27 kΩ resistor. This enables the triggering level referred to the input to the cathode follower to be adjusted from 10 to 36 V. In practice the exact firing level is set by adjusting the helical potentiometer so that the state of the occurrence counter changes at the desired input value.

The discriminator is a long tailed pair with the grid of the second triode directly coupled to the anode of the first. The output at the anode of the second triode has a gain of about 100 over the input of the first triode for the input range 14·5–16·5 V. The circuit has the advantage over a Schmitt trigger that it has no on–off differential, although with very slowly varying input signals this may lead to multiple occurrence counts if the current in V_3 is momentarily held at the value at which the relay chatters.

The 25 kΩ potentiometer is used to adjust the firing level of the circuit to 15·5 V for an unattenuated input.

The counters used are Veeder-Root series 1591. It is not practicable to shunt the inverse voltage spike produced when the counters are switched off as this greatly reduces the counting speed attainable, but although this spike is picked up in other parts of the circuit it does not seem to produce any deleterious results. Under certain conditions, however,

* Mass in grammes of 1000 metres of yarn.

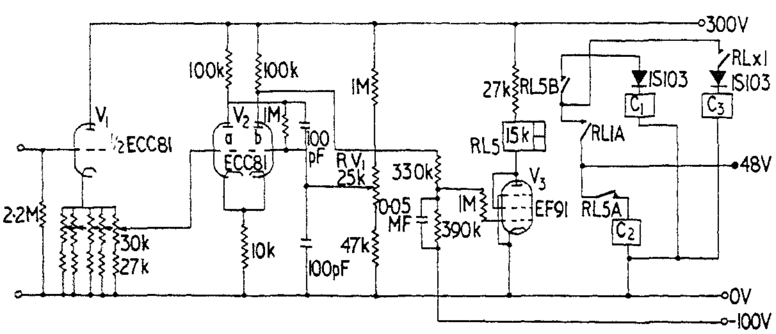

Figure 3. Discriminator circuit. C_1 and C_3, length distribution counters; C_2, occurrence counter.

it is found that this inverse spike may directly cause the loss of counts on the length distribution counters.

The length distribution counters require the coincidence of both the discriminator relay RL5 and the length marker relay RL1 before they operate. If, say, the length counter C_1 associated with discriminator 1 is counting, and, just as the length marker contact RL1A breaks, the relay contact RLX1 of discriminator 2 makes contact, then a conduction loop is provided for the first counter and the current through this is prolonged sufficiently to stop the armature releasing before the length marker contact remakes. The 1S103 diodes connected in series with each of the counters stop them completing this conduction loop for each other.

The operation time of the circuit is largely controlled by the relay and to some extent by the 0·05 μF capacitor in parallel with the grid circuit of V_3. A relay which was tested made contact 3·6 msec after the application of a triggering signal to the cathode follower and broke contact 7·6 msec after its removal. The counters require a signal of approximately 8 msec duration to operate and therefore the signal must fall below the triggering level for a minimum of $7 \cdot 6 + 8 \cdot 0 - 3 \cdot 6 = 12$ msec before a count will be recorded. The instrument is used with the yarn passing at 50 ft min^{-1}, i.e. 1 in. in 100 msec and thus the level must fall for a minimum of 0·12 in. before an occurrence will be counted. For the counter to be de-energized the time will be $3 \cdot 6 + 8 \cdot 0 - 7 \cdot 6 = 4$ msec, equivalent to about 0·04 in. of yarn. As the yarns to be tested will have a minimum average fibre length of 2 in. these distances should not cause any significant error.

The length counters are fed with a train of pulses which persists for the period of the closure of the discriminator relay. However, this period is not in general an integral number of pulses and the ratio of pulse length to the minimum operation time of the counter is important in determining whether a fraction of pulse will be recorded as a count. Moreover, if a pulse just less than that required to register a count is received the armature will move to a position such that the counter has just commenced to operate and on the completion of the pulse it will remain in this intermediate position. If the next train commences with part of a pulse this may well be sufficient to complete the count. Thus there is a maximum inherent error of one digit in the measurement of the average length of the trains of pulses and consequently each digit should be as small a fraction as possible of this length. In the present design the minimum average length is about 2 in. and so with 0·25 in. discrimination there is a maximum error of $\pm 12\frac{1}{2}\%$. In practice there is much more interest in measurements made on trains of an average length of at least 3 in. and, of course, it is unlikely that the maximum error will occur.

The use of 'Dekatron' tubes requiring a pulse of only 120 μsec and with a counting rate of 4 kc/s would enable a much higher yarn drawing speed to be used with a much finer discrimination, for example 100 yd min^{-1} and a pulse every 0·02 in.

(iii) Length marker. The function of the length marker is to produce a pulse every 0·25 in. along the yarn, this pulse operating the length distribution counters and an electronic predetermining counter which controls the length of yarn tested. At the operating speed of 50 ft min^{-1} there are 2400 pulses min^{-1} (the highest speed for the counters is 3000) and this necessitates a photoelectric system. In the present design a disk driven from the yarn drawing gear with 24 holes $\frac{1}{8}$ in. in diameter on a pitch circle of $2\frac{3}{8}$ in. is interposed between the lamp and a phototransistor. The circuits used are mainly from the Ericsson Telephones Ltd. *Electronic Tube Handbook* and these will be referred to by their reference number only.

The essential parts of the circuit are shown in figure 4. The zero resetting switches C1C, C1D and C1E are auxiliary contacts on the contactor of the motor driving the yarn drawing gear. The first part of the switching action occurs when the motor is stopped, the second when the motor is restarted. The nominal test length is 100 yards but the predetermining

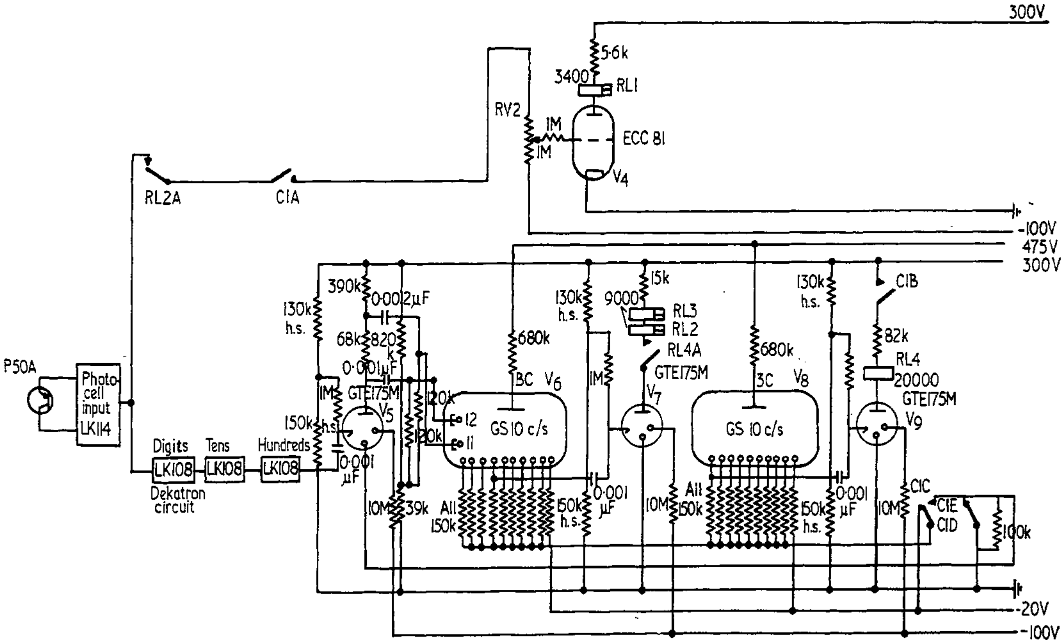

Figure 4. Length marker circuit.

counter is set for 97 yd 8 in. of yarn, i.e. 14000 counts, and after 10000 counts tube V_9 energizes RL4 which in turn applies the 300 v h.t. to the anode of V_7 enabling it to be energized at 14000 counts. The contacts of RL2 and RL3 are used to stop the motor and, as the latter is not instantaneous, to break the train of pulses of V_4. As the process of resetting initiated by the de-energizing of the contactor leads in turn to the de-energizing of RL2 before the motor has completely stopped, the contactor contact C1A is placed in series with RL2A.

RV2 must be adjusted so as to allow RL1 to follow the train of pulses produced by the circuit LK114 and this is best done by trial and error when the equipment is running; it is quite easy to check aurally whether the counters are receiving a steady train of pulses and an accurate check can then easily be made against the 'Dekatron' predetermining counter.

3. Operating conditions

When analysing yarns with capacitative transducers it is vital that they should be conditioned to a known constant and uniform moisture level. To ensure this 110 yard hanks of yarn are conditioned at 65° F and 60% relative humidity for at least 24 hours before test and the tests are carried out in this conditioned atmosphere. Variations in the mean linear density between hanks must be allowed for by correcting all results relative to the mean of the batch of hanks.

The capacitors used with the apparatus are very rigidly constructed and a calibration in terms of the linear density of the yarn is required for each one. This is done by noting the output of the capacitance comparator for a given piece of yarn, cutting out this piece and weighing it on a torsion balance.

When running the instrument the indicating meter of the comparator presents a variable impedance, due to the back e.m.f. generated by movements of the coil, and it must either be switched out of the circuit or a buffer stage must be provided.

4. Experimental results

In the introduction it was stated that it was necessary to determine both the dispersion and structure of a waveform. The results from the length counters give the cumulative distribution of the yarn mass and the occurrence results enable a description of the structure to be made.

4.1. *Length distribution*

The length results are expressed as a percentage of the test length and in figure 5 the cumulative frequency distribution of a jute yarn is shown plotted on an arithmetical probability scale. The yarn has a linear density of 320 Tex.

A normal distribution would appear as a straight line but it will be seen that this yarn has a positively skewed distribution. The upper end of the curve shows the incidence of thick places and the lower end the incidence of thin places and as previously indicated these parts of the distribution have a marked influence on the performance of the yarn.

4.2. *Occurrence results*

The occurrence counters record the number of pieces into which the length at any given level is broken and the results may either be presented as the number of occurrences or the average length above a level. The latter method has been adopted and its variation with linear density for the 320 Tex jute yarn is shown in figure 6. The average length below a level may also be computed and the variation of this quantity with linear density is also shown in figure 6.

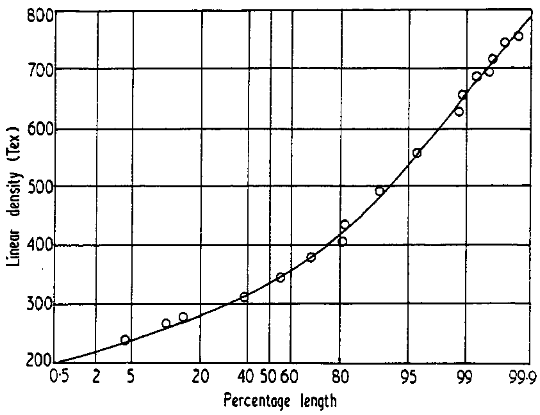

Figure 5. Length distribution curve for 320 Tex jute yarn.

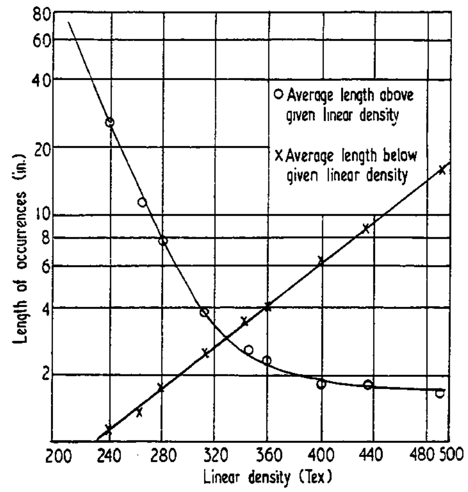

Figure 6. Average length of occurrences for 320 Tex jute yarn.

The curve of average length below a given level shows the nature of the thin places and figure 6 shows that log (average length) has decreased linearly with linear density down to 230 Tex. At 230 Tex the places have an average length of 1·0 in. In contrast, examination of the curve of average length above a given level shows that thick places are virtually constant in length, at 1·8 in., above 400 Tex.

The two curves cross at 330 Tex, which is approximately the median linear density, and the average length of an occurrence at the median is 2·8 in. Further work is required to establish the influence of various factors on the average length of an occurrence and on the length of occurrences at the tails of the distribution and to relate these properties to the practical performance of the yarns. However, initial experiments have confirmed the expected trend of increasing average length of occurrence with increasing length of fibre in the yarn.

5. Accuracy

In tests on jute yarns, with a coefficient of variation between 1 in. lengths within 100 yards of about 20%, it has been found possible to produce very consistent length distribution curves by testing 20 hanks of 100 yards length. The required accuracy is greatest in the tails of the distribution but the linear density, above which lies any given percentage of length, can be found with a reproducibility of 6·9 Tex on a 320 Tex yarn, i.e. 2·2% of the mean linear density.

Acknowledgments

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References

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Notes and news

Computers in the space age

The 1962 Fall Joint Computer Conference will be held from 4th to 6th December 1962 at the Sheraton Hotel, Philadelphia, Pennsylvania.

The theme of the conference will be 'Computers in the space age' and the following topics will be covered: Information processing in space technology, Advanced system organizations, Hardware–software relations, New applications of information processing, Information processing as a national resource and Information communication and display.

Further information may be obtained from E. G. Clark, Chairman, Program Committee, Burroughs Corporation, Research Center, Box 843, Paoli, Pennsylvania.

Units and standards of measurement employed at the National Physical Laboratory

We have received from the National Physical Laboratory copies of two booklets in their series 'Units and standards of measurement employed at the National Physical Laboratory'. These are a completely revised edition of Booklet No. 1, *Length, mass, time-interval and frequency*, and Booklet No. IV, *Temperature*.

These booklets are published for the Department of Scientific and Industrial Research by Her Majesty's Stationery Office, price 1*s*. 6*d*. each. The others in the series are entitled *Light photometry, colorimetry and radiometry* (No. 2) and *Electricity* (No. 3).

U.S. National Bureau of Standards

The U.S. National Bureau of Standards have announced the following new publications:

Calibration procedures for direct-current resistance apparatus, National Bureau of Standards Monograph 39, 40 cents.
Thermocouple materials, National Bureau of Standards Monograph 40, 30 cents.

These are available from the Superintendent of Documents, U.S. Government Printing Office, Washington 25, D.C.