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RECORDER WITH AUTOMATIC SCALING FUNCTION

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Abstract : We discuss what kind of scale is suitable for analog signal recording paper from the viewpoint of human engineering. We show a method for automatically generating a suitable scale from the higher and lower limits of the recording range.

1. Introduction

Microprocessor-based hybrid recorders with digital printing and waveform recording capabilities appeared in the market some time ago. Some recorders of this type automatically print the scale which had previously been preprinted on the paper. However, the type of scale had to be specified by the user from a limited selection. Time was spent investigating what type of scale was needed, and a new scale selection was required each time the measuring range changed.

We have developed a recorder which automatically determines the scale from the measuring range, after investigating which type of scale is easy to read and determining a method to realize it.

2. Scale

The scale is indispensable for analog display and analog recording. Since an analog quantity is continuous, "reading" it from a display or recording depends on a reference value criterion provided by scale.

According to JIS Z 8103, "scale" is defined as a group of lines or points shown along a certain line to indicate the quantity, and may include numbers and symbols as required.

That is, the scale is an aggregation of lines or points indicating a quantity by position with numbers and symbols for reference. Here the lines or points will be called "scales marks" and the numbers and symbols "scale numbers". In reality scale marks are arranged in some type of pattern for easier understanding, for examples, there may be a major mark called "main scale mark" and a smaller one called "subscale mark". For our purpose we will use a large scale mark, medium scale mark and small scale mark, named with respect to their respective sizes of scale spacing. The spacing between two adjacent scale marks is called then "scale spacing" and the difference between maximum and minimum scale mark is the "scale span".

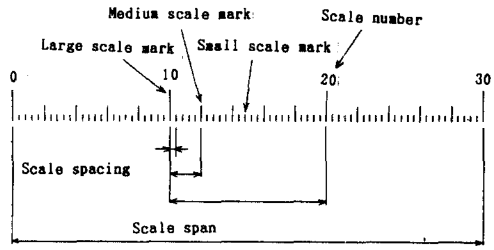

Fig.1 Scale

3. Ideal scale

What is required of a scale on the recording paper of a recorder? Accurate, easy and quick determination of the value of a certain point of the recorded waveform.

We now analyze the procedure for taking a scale reading.

(1) Find the two nearest scale numbers enclosing the position to be measured.
(2) Find the scale marks associated with the two scale numbers found in step (1).
If there are no other scale marks between them, go to (3).
If there are scale marks between them, determine the values expressed by the two nearest scale marks enclosing the position to be measured.
(3) Estimate a value somewhere between the values of two nearest scale marks enclosing the position to be measured. This is the so-called "rule of thumb" method.

For example, with the scaling in Fig.2, step (1) in the procedure places the value to be measured between 30 and 40. Four unnumbered scale marks are present between marks "30" and "40". Following step (2) in the procedure, the values expressed by the two nearest scale marks enclosing the position to be measured are determined. In this figure, the difference of 10 between 30 and 40 is divided into 5 parts giving a scale spacing value of 2. The scale mark to the left of the position to be measured is therefore determined to be 36, and the scale mark to the right is 38. Continuing with step (3) of the procedure, the rule of thumb is used to estimate a value between 36 and 38. The point being measured is located about halfway between, so the value is read as 37.

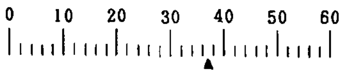

Fig.2

Accuracy in reading a value can be improved, that is, the reading error can be minimized, by making the scale spacing smaller. If it is too small, however, time required to determine the value of the scale mark itself increases. This time can be reduced if all scale marks have scale numbers, but this is not practical and so is necessary to count marks from the nearest numbered mark to the target value. A small scale spacing makes this task time consuming and difficult. By this reasoning then, there can exist easy-to-read and difficult-to-read scales even if their scale spacing is the same.

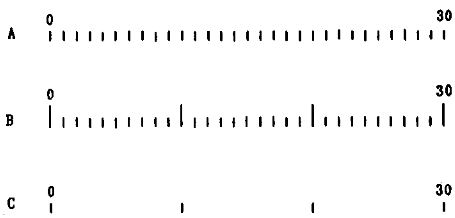

Fig.3

In Fig.3, A and B have the same scale spacing, but B is easier to read because step (2) in the procedure for scale reading is more easily and quickly done. Scale A takes more time to read, and there is a danger of making a mistake in step (2). Similarly, C, whose scale spacing is 10 times larger than A or B, can be said to be a good scale.

Then, what are the conditions for obtaining a good scale? Let's start with the scale number. The following rule can be applied :

Rule 1 As many scale numbers as possible should be provided within a range without making the recording paper difficult to read.

For example, Fig.4, B is easier to read than A.

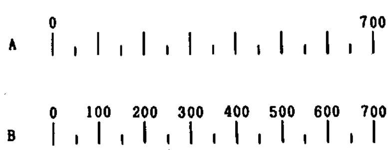

Fig.4

The following discussion will proceeded limiting to linear scale. If a section is divided by too many scale marks of a uniform pattern, the marks must be counted to know how many divisions are in the section, as in A of Fig.3. What is the maximum number of divisions that can be known by observation without counting? We performed a test in which subjects were shown several sections of uniform length, but with varying numbers of divisions (see Fig.5) for a short time (0.5 seconds). Most of the subjects could recognize up to 5 divisions without counting.

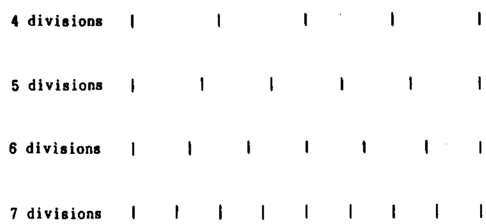

Fig.5

In the decimal number system, the number 5 is a convenient number, being half of 10, as is the number 2 also an even divisor 10. Therefore, the following rule can be made :

Rule 2 The basic numbers of division between scale numbers are 2 and 5.

From this and (Rule 1), it can be said that the scale numbers should be selected from a sequence of numbers which satisfy the following two conditions :

(1) The sequence of numbers for scale division is expressed by "1 or 2 or 5 ($\times 10^N$)"
(2) The sequence of numbers includes "0"

Good example :

..... -0.5 0 0.5 1.0 1.5 ....
..... 250 252 254 256 258 ....

Bad example :

..... 110 160 210 260 310 ....

Whether 2 or 5 is selected as the division number depends on the values of numbers at each end of the division. Since scale numbers are provided at a spacing of 1 or 2 or 5 ($\times 10^N$), the following is adopted :

In case of 1 $\times 10^N$ ...division number=2 or 5
In case of 2 $\times 10^N$ ...division number=2
In case of 5 $\times 10^N$ ...division number=5

This rule provides the conditions necessary for easy reading in step (2) of the procedure above.

For step (3) of the procedure, scale spacing should be made smaller. If the scale spacing is too wide with either division number 2 or 5, and the rule of thumb reading error becomes large, it is effective to use multiple scale patterns. That is, fine reading is made possible by making an intuitive reading of the division numbers from a hierarchical structure. How many hierarchical levels are proper? With too many, it becomes necessary to remember the spacing of each hierarchical level.

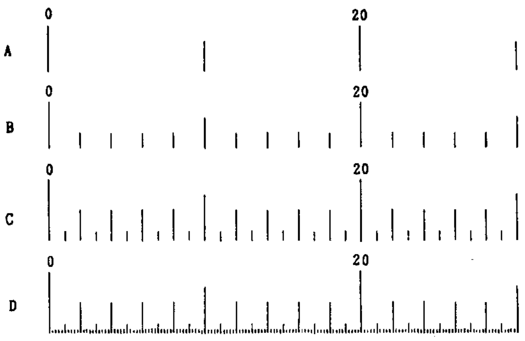

Fig.6

For A and B in Fig.6, the spacing is easily known, but for C and D it is necessary to count.
Therefore, the number of levels is preferably limited to 2, and the scale spacing for the smallest scale mark should not be so small that reading it with the human eye is difficult. This leads to Rule 3 as follows :

Rule 3 Between two scale numbers, a maximum of 2 types of scales (2 hierarchical levels) should be used, and the section should be divided into as many marks as possible without sacrificing ease of reading.

The above three rules are important in obtaining a proper linear scale for the recording paper.

4. Constraints in Reality

In development of the recorder, the number of scale patterns was limited to 3 due to the expressive constraint. That is, the scale marks consist of three types: a large scale mark, a medium scale mark and a small scale mark. About the large scale mark it was decided a maximum 12 was possible. A scale number should be attached to every large scalemark, but in our case 8 was chosen to avoid difficulty in reading the scale, in accordance with Rule 1.

5. Deciding Method

The following shows the decision logic for creating a scale division in the recorder. Limitations are that it is must be a linear scale, and it is made from the lowest and highest values of the scale(the highest and lowest values may be fractional values).

The lowest value of scale (SL) and highest value of scale (SH) are decimal numbers consisting of 4 digits for the integral part and 1 digit for the decimal part (if they cannot be expressed in this form, they must be expressed in combination with the "characteristic of unit" available as the scale facter). On the basis of the SH and SL, then the scale division of the linear scale is may be determined.

First, the scale span (SHL), that is the difference between the highest and lowest value of scale, is found.

$$SHL = SH - SL$$

The scale span is then divided into a fixed-point part (SHL_{FIX}) and exponent part (SHL_{EXP}) with the provision that SHL_{FIX} is a number not less than 100 and not more than 1000.

$$SHL = SHL_{FIX} \times 10^{SHL(EXP)}$$

From SHL_{FIX} the fixed-point part of the scale spacing is determined in accordance with Table 1.
The values in Table 1 are a reflection of the three rules. To meet the Rule 1, a maximum of 12 scale numbers was decided on for the recorder in consideration of the paper width (180mm) and the size of the character used for the scale number (In reality, however, the numbers were not attached to all the large scale marks but to a maximum 8 marks as mentioned above). From the table, spacing between large scale marks corresponding to SHL_{FIX} in the range of 100 to 1000 is found. Once the value of the large scale mark spacing has been determined, the division numbers (or scale spacing) of the medium and small scale marks follows from Table 1.

Table 1 Scale Span/Scale Spacing of Scale Marks

Fixed-point part of scale span SHL_{FIX}	Fixed-point part of spacing of large division mark LW_{FIX}	Fixed-point part of spacing of medium division mark MW_{FIX}	Fixed-point part of spacing of small division mark SW_{FIX}
$100 \leq SHL_{FIX} < 110$	10 (10-11 div)	5 (2 div)	1 (5 div)
$110 \leq SHL_{FIX} < 150$	20 (6-8 div)	10 (2 div)	2 (5 div)
$150 \leq SHL_{FIX} < 210$	50 (3-5 div)	10 (5 div)	2 (5 div)
$210 \leq SHL_{FIX} < 460$	50 (5-10 div)	10 (5 div)	5 (5 div)
$460 \leq SHL_{FIX} < 1000$	100 (5-10 div)	50 (2 div)	10 (5 div)

The process after scale spacing are decided from Table 1 is as follows :

What is expressed by $LW_{FIX} \times 10^{SHL(EXP)} \times N$ (N : integer) and SL or higher and SH or lower
.... position of large scale mark
What is expressed by $MW_{FIX} \times 10^{SHL(EXP)} \times N$ (N : integer) and SL or higher and SH or lower
.... position of medium scale mark
What is expressed by $SW_{FIX} \times 10^{SHL(EXP)} \times N$ (N : integer) and SL or higher and SH or lower
.... position of small scale mark

The following explains how to attach scale numbers to some of the large scale marks using Table 2 and Table 1.

Table 2 Scale Span/Scale Number Spacing

Fixed-point part of scale span SHLFIX	Fixed-point part of scale number spacing NWFIX
100 ≤ SHLFIX < 110	20 (5-6 div)
110 ≤ SHLFIX < 150	20 (6-8 div)
150 ≤ SHLFIX < 210	50 (3-5 div)
210 ≤ SHLFIX < 360	50 (5-8 div)
360 ≤ SHLFIX < 460	100 (4-5 div)
460 ≤ SHLFIX < 710	100 (5-8 div)
710 ≤ SHLFIX < 1000	200 (4-5 div)

From Table 1 and 2, it is known that scale numbers are attached either to all large scale marks or to every other large scale mark. When attached to every other large scale mark, a sequence of numbers which can be divided by the scale number spacing is selected.

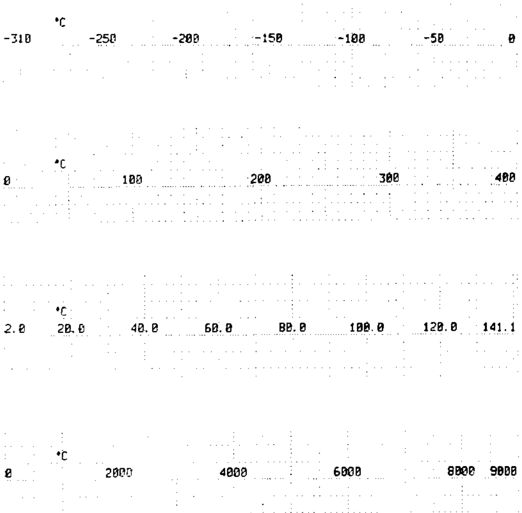

Fig.7 Scale Recording Example

Fig.7 shows some examples of scales generated by the process described above. An actual recording is shown in Fig.8. It is known that proper divisions were made depending on scale spacing taken from Table 1.

On actual recording paper, the tag, unit, expornent part of unit, recording color of waveform, etc. are recorded in addition to the scale. When multiple measurements with different measuring ranges are recorded on the same recording paper, the scale is changed as needed according to a certain cycle as shown in Fig.8.

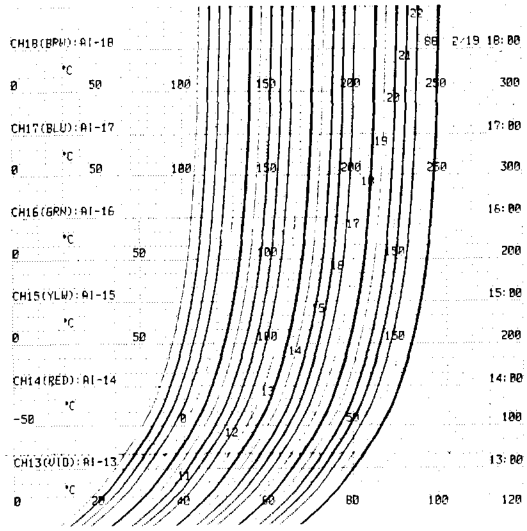

Fig.8 Scale Recording Sample

Photo 1 shows an external view of the recorder.

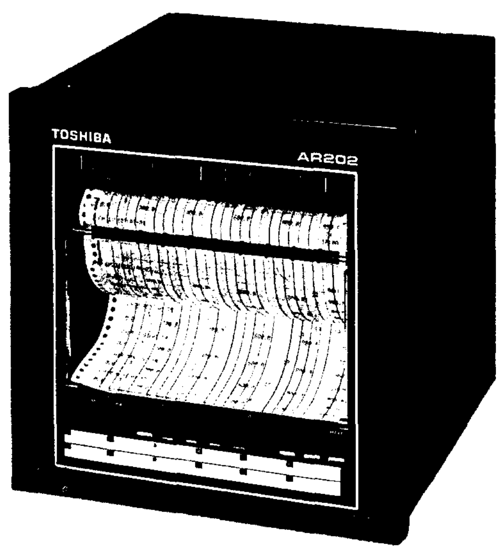

Photo 1 External view of the recorder

Fig.9 shows the hardware diagram for the recorder. Each input from a maximum of 24 analog signals is read sequentially through a multiplexer, and plotted by a penwheel with 6 color tips. The penwheel is carried on a carrige which moves across the paper every 15 seconds. The CPU is an 8-bit microprocessor, type 8085A, which controls all parts of the recorder. The scales are printed by a serial type thermal head mounted on the carriage. The thermal head stops at the position where the scale mark is required, and a heat element (resistor) is energized to print the scale mark on heat-sensitive paper.

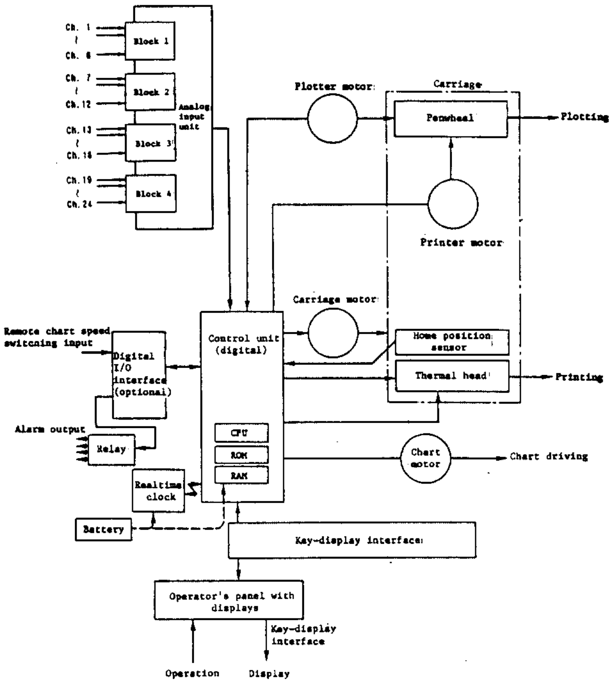

Fig.9 Hardware Diagram

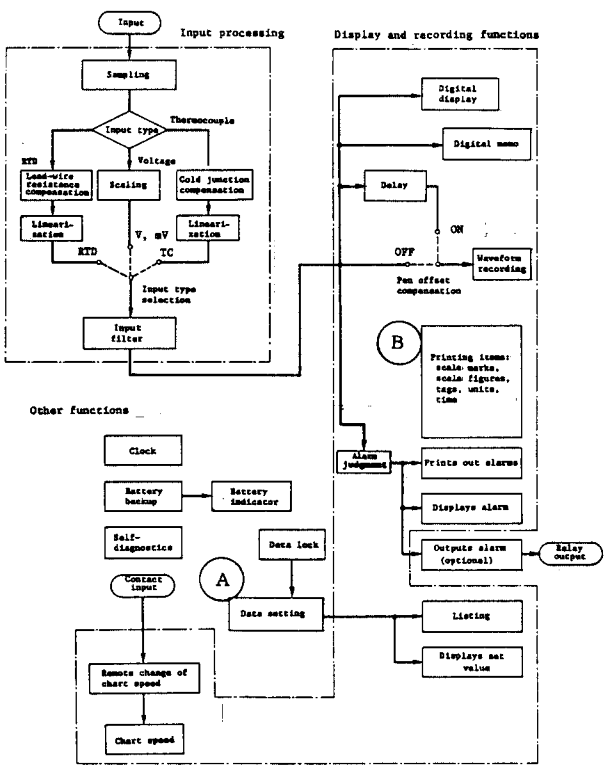

Fig.10 Software Diagram

Fig.10 shows the software diagram. The program for automatic scaling is in the block A and occupies about 4Kbytes of program memory. The program is not excuted periodically as input signal processing is, but only when a new recording range is set by key pad on the operation panel. A new scale is then generated and stored in RAM, which is backed up by battery. The scale is printed periodically by the print program in block B.

Table 3 shows the principal specification of the recorder.

Table 3 Specifications

Number of inputs : 6,12 or 24 points
Input signals : two types as following
(1)dc voltage and thermocouple type

dc voltage	mV	-999.9～999.9 mV
	V	-50.0 ～ 50.0 V
Themocouple (JIS/IEC)	B	0 to 1820 ℃
	R	-50 to 1769 ℃
	S	-50 to 1769 ℃
	K	-270 to 1372 ℃
	E	-270 to 1000 ℃
	J	-210 to 1200 ℃
	T	-270 to 400 ℃
	N	0 to 1300 ℃

(2)Resistance bulb (RTD) type

Pt100Ω (JIS/IEC)	-200 to 650 ℃

Measuring cycle : 15 sec ／ 6 points
Power supply : 85 to 264 Vac, 47 to 66 Hz
Power consumption : Maximum 40 VA
Number of recording points : Same as number of inputs.
Recording device : Penwheel (6 Colors)
Dot interval : 15 sec ／ 6 points
Accuracy : ±0.25 %FS (Digital display and printing for a range 0 to 5 V)
Chart speed : 10,20,30,60,120,180,200,360,600,1200 mm/h
Recording paper : Thermal type
Shape - Fanfold
Printing color - Black
Width - 210 mm
Length - 16 m

7. Conclusion

We have discussed what kind of scale is suitable for recording paper from the viewpoint of human engineering. We also discussed a method for generating the scale automatically from the higher and lower limits of the measuring range. Although such human factors as "easy-to-read" can not be uniformly determined, we think we have realized a practical scale sufficient for normal use. We will continue our efforts to improve it.

Reference

[1] M.Tohara and Y.Kanda : Hybrid Recorder AR202, Instrumentation & Automation, Vol.16, No.9,(1988)