Training of Auditory Reception by Radio Telegraphists

(Das Anlernen der Höraufnahme durch Funkentelegraphisten)

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[Additions and explanations are added in square brackets]

Short summary of findings:

1. Professional telegraphists or radio operators are expected to be able to receive Morse code with a speed of 100 to 125 characters per minute (CpM) [or 20 to 25 words per minute (WpM)].
2. Typically, and until now, training was started with a slow speed of 30 CpM [6 WpM]. This had the consequence that subjects started to memorize the individual characters by their atomistic structure. Later, when speed was increased, they had to re-learn the characters as an individual pattern ('Gestalt').
3. A new method is described, whereby the characters are presented from the start as indivisible patterns.
4. At the Psychotechnical Lab of the Dutch P.T.T., two subjects were trained with this new method. And it was found that about 44% less time was needed as compared to typical subjects trained with the standard method.

Contents

1. Reception by Ear

The work of telegraphists is divided into two parts, and both are equally important: sending and receiving. On mainland telegraph stations these tasks are nearly always performed by dedicated equipment. But telegraphists working on ships, airplanes or coastal stations spend their working time performing these tasks by themselves. In this paper we only cover the code reception by ear, the sending of code will be covered in a subsequent paper.

International agreements have determined that for radio operators two different certificates shall be issued. The 2nd class certificate requires that a telegraphist shall be able to receive 100 characters (20 groups of 5 characters each) per minute with text in his native language, and 80 characters (16 groups) per minute with coded [nonsense] text. The 1st class certificate requires the reception of 125 characters (25 groups) [per minute] in native language and 100 characters (20 groups) [per minute] in coded [nonsense] text.

A long training time is needed to reach such a high speed. With the currently used training method, one starts with a low number of characters per minute, typically 30. Then the speed is slowly increased until the desired limit is reached.

It is generally known that Morse code symbols are composed of dots and dashes. During reception by ear, one hears singing or buzzing tones of different length, depending on the reception device. But at higher speeds (starting with about 80 characters [per minute]) one no longer hears a succession of shorter or longer tones. Instead, each symbol is heard as a rhythmic pattern ('Gestalt') of characteristic shape. For the trained ear, these patterns are very different and therefore mistakes occur only seldom. As soon as a telegraphist hears such a 'Gestalt', he has to select one symbol from the set of symbols known to him. Initially, this selection process takes much time, but in the course of training this selection becomes faster and more reliable. And while the selection process is done consciously at the beginning, later it becomes more and more automatic. So one can speak of a skill that needs to be trained. But not everyone has the right predisposition to develop such a skill, therefore candidates should first be put through a qualifying examination.
In (1) I have reported on such an examination for radio telegraphists.

2. The Old Training Method

After well predisposed candidates have been selected, the remaining task is to guide them fast and comfortably to reach the goal. And the goal is a fast choice (at 125 characters per minute) between known auditory patterns. It seems logical to allow for a longer interval for this choice at the start, and then gradually shorten that interval. At the start of the training, the candidate should have the chance to memorize exactly the same auditory patterns that he will hear at the end of the training.

Until now, this has not been the typically applied training procedure. True, the number of choices per minute [a candidate had to do] were reduced initially, but this was achieved by slowing down the complete sending process and extending it over a longer time span. The ratios between character duration and intervals between characters or words were kept unchanged. When the overall speed was reduced [from 120] to about 30 characters [per minute], then the intervals between characters and words were increased by a factor of 4. And at the same time the length of the complete Morse character was increased, by increasing the length of each dit, dah and inter-element space by a factor of 4.

A consequence of this increase is that the auditory character of the Morse character is completely lost. The character is no longer a rhythmic 'Gestalt', but falls apart into a sequence of longer and shorter tones. This sequence can and will be perceived in an atomistic way. Counting of dits and dahs becomes unavoidable. The subject is pushed to start guessing the outcome while the sequence is still going on.

This counting and this atomistic perception are only possible up to a certain speed. And this speed seems to be different for different subjects, and seems to be lying between 80 and 100 symbols per minute. When a subject comes near to this limit, he must drop the familiar procedure and get used to a completely new way of perception and choice between rhythmic 'Gestalt' patterns. This change of procedure can be seen in the curves for auditory reception, where plateaus develop that extend over a large number of training sessions. These plateaus can be seen in curves 3 to 5 in Fig.1, representing the old training method.

Therefore, one cannot say that the traditional training method had been an easy way to reach the goal. On the contrary, it is a very tough way to go. From session to session not only the number of possible choices is increased, but also the items between which the choice has to be made are constantly changing their characteristics. And half-way down, the characteristics are changed fundamentally [from atomistic to Gestalt]. We should not be surprised to see, that thereby the way to reach the goal tends to be quite long.

3. The New Training Method

I have tried to define a new learning method, whereby the unnecessary difficulties of the old method are avoided. With this new method the indecomposable sound patterns are presented right from the start of training and remain unchanged until the last session. Initially, they are presented with long inter-character intervals, and only these intervals are shortened during training until they have reached the standard interval length.

To facilitate this, an automatic Creed Morse Transmitter was used. In this machine a punched tape runs at a constant speed of 160 cm/min, which corresponds to a speed of 125 characters/min. Now, at the start of training, up to 5 blank spaces are inserted between individual Morse characters. The number of additional blank spaces is subsequently reduced to 4, 3, and down to zero.

When further on we talk about “Interval 2”, then the normal inter-character space after a Morse character is meant, with one additional blank space. “Interval 3” means the normal inter-character space plus two additional blank spaces, and so on.

The following tables show some figures that characterize the old and the new training method. All timing values are given in terms of “Reversals” ([regular] current reversals within the Creed transmitter) or “Rev”. Such a “Rev” corresponds to the distance between the small perforation holes in the centre of the Creed tape, which are used for transportation of that tape.

A. [Details of Creed Tape]

When the Creed transmitter is adjusted for 125 char/min, then 632 Rev are run in 60 seconds	1 Rev = 0.095 sec
Normal inter-character space [3 elements]	3/2 Rev = 0.14 sec
One blank space [additional 4 elements]	2 Rev = 0.19 sec
With 125 char/sec we then have for 60 sec:	
125 inter-character spaces 125 x 0.14	= 17.5 sec
125 x average character length [w/o space at the end]	= 42.5 sec
Average character length 42.5 / 125	= 0.34 sec

B. [Intervals between Characters]

With “interval 1” the time span between characters is [3/2 Rev]	0.14 sec
With “interval 2” the time span between characters is [3/2 + 2 Rev]	0.33 sec
With “interval 3” the time span between characters is [3/2 + 4 Rev]	0.52 sec
With “interval 4” the time span between characters is [3/2 + 6 Rev]	0.71 sec
With “interval 5” the time span between characters is [3/2 + 8 Rev]	0.90 sec
With “interval 6” the time span between characters is [3/2 + 10 Rev]	1.09 sec

C. New Training Method

Interval 6	[average] Character 0.34 s	Interval 1.09 s	Number of chars 42 [speed = 25/8.4 WpM]
Interval 5	[average] Character 0.34 s	Interval 0.90 s	Number of chars 48 [speed = 25/9.6 WpM]
Interval 4	[average] Character 0.34 s	Interval 0.71 s	Number of chars 57 [speed = 25/11.4 WpM]
Interval 3	[average] Character 0.34 s	Interval 0.52 s	Number of chars 70 [speed = 25/14 WpM]
Interval 2	[average] Character 0.34 s	Interval 0.33 s	Number of chars 90 [speed = 25/18 WpM]
Interval 1 (normal)	[average] Character 0.34 s	Interval 0.14 s	Number of chars 125 [speed = 25/25 WpM]

D. Old Training Method

4 x slower	[average] Character 1.36 s	Interval 0.56 s	Number of chars 31.25
3 x slower	[average] Character 1.02 s	Interval 0.42 s	Number of chars 41.66
2 x slower	[average] Character 0.68 s	Interval 0.28 s	Number of chars 62.5
4/3 x slower	[average] Character 0.45 s	Interval 0.19 s	Number of chars 93.75
not slower	[average] Character 0.34 s	Interval 0.14 s	Number of chars 125

It has already been mentioned as a first advantage of the new training method, that the auditory patterns stay unchanged from the beginning to the end of the training.

A second advantage is shown by the numbers in the tables above. The relation between interval and character is much more advantageous for the new method as compared to the old one. For the old method this relation has a constant value of 2:5, while for the new method this relation has a value of 3:1 for the slowest overall speed, and still a value of 1:1 for a speed of 90 characters [per minute]. With the old method, the largest interval has a value of 0.56 [sec] at a speed of 31 ¼ characters per minute. With the new method such an interval length is only reached at an overall speed of 70 characters per minute.

With the new method, the period of time in which the subject has to make a decision is very long, especially at the beginning of the training. The character itself is so short and perceived as an entity, that the subject is not tempted to think about what may come, while the character is sounded. The legitimately feared fantasizing is thus made impossible.

Incidentally it should be mentioned that a second form of fantasizing, the imagination of the message, is suppressed by only using languages unknown to the subjects or coded [nonsense] messages up until “interval 2”. The subjects trained with the new method got used to perceive a message as a sequence of sound patterns, which had to be decoded one by one. Thereby only few errors were made and garbling of whole groups [of characters] was an exception. Until the last training session, the subjects made less errors when receiving coded [nonsense] messages as compared to receiving clear text in their native language. This seems to leave the division into different classes of difficulty in the international agreement [reported above] as unfounded.

4. Application of the New Method

At the Psychotechnical Lab of the Dutch P.T.T. in Den Haag a few subjects were trained using the new method. The results are shown in Fig. 1. The subjects underwent the qualifying examination described in (1), and were taken from a group of young precision mechanics and electricians, employed by the Central Telegraph Workshop in Den Haag and by the Central Telegraph and Telephone Office. As I wanted to compare the results with those of students attending the School for Telegraphists in Amsterdam, being trained with the old method, I chose subjects of approximately the same age. The education level of my subjects was slightly lower, especially with regard to foreign languages.

The students in the school in Amsterdam basically had the whole day for training sessions. In the first month’s, training was scheduled for 3 hours a day, and later for 2 hours a day. Classes were held from 9 to 12 a.m. and from 1 to 4 p.m. My students were young employees who worked for 48 hours a week. For my experiments they were available every day from 11 to 12 a.m. and from 2 to 3 p.m. (just before and after lunch break). At the start of the first session, they already had worked for 3 ½ hours, and often done quite tiring work. Therefore, with respect to tiredness of my students, I was not in a very favourable position.

I started with three subjects, but after just a few hours one of them fell behind. I tried to remedy this by giving this subject more training hours as compared to the others. But as it became apparent that the lag even increased, I had to dismiss this subject. I consider his initial selection on grounds of the qualifying examination to be an indication of a flaw in that process. A process that cannot be expected to be 100% precise. So, until the end of the experiments, I was left with two subjects.

Training was started with “interval 6”, which is equivalent to an overall speed of 42 characters per minute [8.4 WpM]. As usual, the Morse characters were trained in groups of characters with similar patterns. Other characters were only introduced when that group was completely mastered. Learning seemed easy at this speed. Several different groups of characters were presented right at the beginning, with the aim to train all characters as soon as possible. There should not be a chance to develop a difference between “difficult” and “easy” characters (read: seldom and often heard characters). It turned out that indeed no single character is more difficult than the others. Each student seems to have their own special characters that they

confuse, and these characters are indeed different for each subject. By returning and repeated training of the related group of characters, these errors can be almost completely eradicated. What then remains are errors due to not mastering a certain speed.

While I wanted to compare my results with those of the School for Telegraphists in Amsterdam, I used the same total number of characters, namely 40. Some characters are almost never used in mainland telegraph service, and in Amsterdam these are trained after the main training is done. While I do not agree with this separation, I had to use the same procedure in order to get comparable results. While the School for Telegraphists in Amsterdam takes the actual number of trained characters easy, they are very strict in terms of counting any errors. Each wrongly decoded character and each missing character are counted as an error. Obviously, I also adopted the same strategy for error counting.

Training was started with “Interval 6”, first with character groups and gradually with mixed characters, until all characters were mastered equally well. As a measure of mastery at “Interval 6” it was assumed that the subject should have delivered at least one sample session per day with 1% or less errors. The samples were taken randomly from the training sessions, neither student nor trainer did know in advance, which sample would be taken. Thereby it was assured that the students would exert themselves to avoid spoiling the results of a whole session by just a few minutes of distraction. Such training is very strenuous and therefore I eventually reduced the training time to one hour per day, as the additional second hour did not produce significantly better results. Very strenuous work should not be done during many hours a day, one hour is sufficient for auditory reception, provided the most is made of this time span. And, by the way, a significant part of this remaining one hour was allocated to relaxation at the discretion of the trainer.

The same measure of mastery (1% errors or less) was applied when going from “Interval 5” to “Interval 4” and so on. For reaching the (final goal) of 125 characters/min [25 WpM], the requirements were significantly increased. Now in 2 of 4 consecutive sample sessions the errors should amount to 0.5% or less.

Training was done consecutively with interval 6, 5, 4, 3, 2, and with normal interval. The different levels reached are shown in Fig. 1. The dots in curves 1 and 2 correspond to measured values, while the values in between are interpolated by curve fitting. Training proceeded very well and fast until the final step had to be made, the transition from 90 characters/min [18 WpM] to 125 characters/min [25 WpM]. This transition turned out to be very difficult. Therefore I would have liked to add an intermediate step with “Interval 1 ½“ (103 characters/min). But when I asked if such a [Creed-] tape could be prepared for me, I got a negative reply. Only later it turned out that this answer had been given mistakenly, as it is indeed possible with the Creed-perforator to generate intervals with length 1 ½ (normal interval + ½ blank space). Therefore, in a further experiment, the intermediate speed of 103 characters/min [18 WpM] will be included.

Subject H., a very energetic young man, was able to overcome the difficulties when going directly from 90 to 125 characters/minute, his error rate decreased from day to day. Unfortunately, he could not finally reach the level of 125 characters/min, as he had been scheduled for military service. He had not yet fully reached the error level of 0.5%, but would have reached that level within a few further training hours. The last level that he did reach, was calculated as 122 characters/min [24.4 WpM].

Curve 1 in Fig. 1 was extended to 125 with the same curvature, ending at 153 total training hours.

The second subject J. is physically and mentally very sensitive. At the start of the training, he had an attack of flu, from which he suffered much. The curve with his results crosses the curve for subject H. at the 120th training hour at an (interpolated) level of 116 characters [per minute], but then a bad relapse occurred. The subject complained about the mental demands that were put on him, while at the same time a large rebuilding was going on in the Telegraph Office, and he had to carry heavy materials. This was very tyring for him, as he was not used to physically hard work. I therefore think, that his physical tiredness contributed to the relapse.

First, training was stopped for a while, then resumed with care. To make it easier for the subject, training was resumed using the old method at a level of 110 characters/min [22 WpM] and then increased to 125 characters/min. That level was reached after the 176th training hour. It [the switching to the old method] should not be seen as weakness on my side. After all, the new method should only be applied as long as it is advantageous and less demanding. The curve for subject H. shows a flatter trend at the highest level and thereby confirms that the last step is very large and difficult. It seems appropriate for future training sessions to switch from “Interval 1 ½“ (103 characters/min) over to 105 characters/min with the old method, and then do the last part of the training with the old method. This has the additional advantage, that the subjects can get used to speeds between 100 and 115 characters/min [20 to 23 WpM] that are used in daily telegraph practice. The speed of 125 characters/min [25 WpM] is to be seen as a goal for final examination, but never demanded in practice.

5. Training Results for the Old Method and the New Method

Fig. 1 allows to compare between the old and the new method.

From 1928 until 1930, the School for Telegraphists in Amsterdam has trained 41 subjects without any prior skills of auditory reception (These subjects have been taken from a larger group, from which 65% had been sorted out as unsuitable). For each subject a curve was drawn that showed the training results. In Fig.1 curves are shown for the top-level subject (No 3), for the bottom-level subject (No 5), and for an intermediate level subject (No 4). This last curve ends at the 297th training hour, while the calculated mean level was 293.6 training hours.

But it has to be understood that curves 3 and 4 show exceptional results. It turned out, that only 9.8% of subjects had a training time below 240 hours, and only 12.1% needed a training time in excess of 340 hours. The remaining 78.1% needed between 240 and 340 hours of training time, and their individual time spans were equally distributed over that interval.

We can therefore compare the 153 and 176 training hours of the two subjects with those 240 and 340 hours of the large central group of students. Indeed, we have only trained two subjects, but it is very unlikely that both belong to the 9.8% of very talented students. When we therefore treat them as belonging to the middle group, then we have a gain of about 44%. This figure would certainly have been larger, when the training level with 103 characters/min speed could have been used, and when, after reaching this level, training would have been switched to the old method.

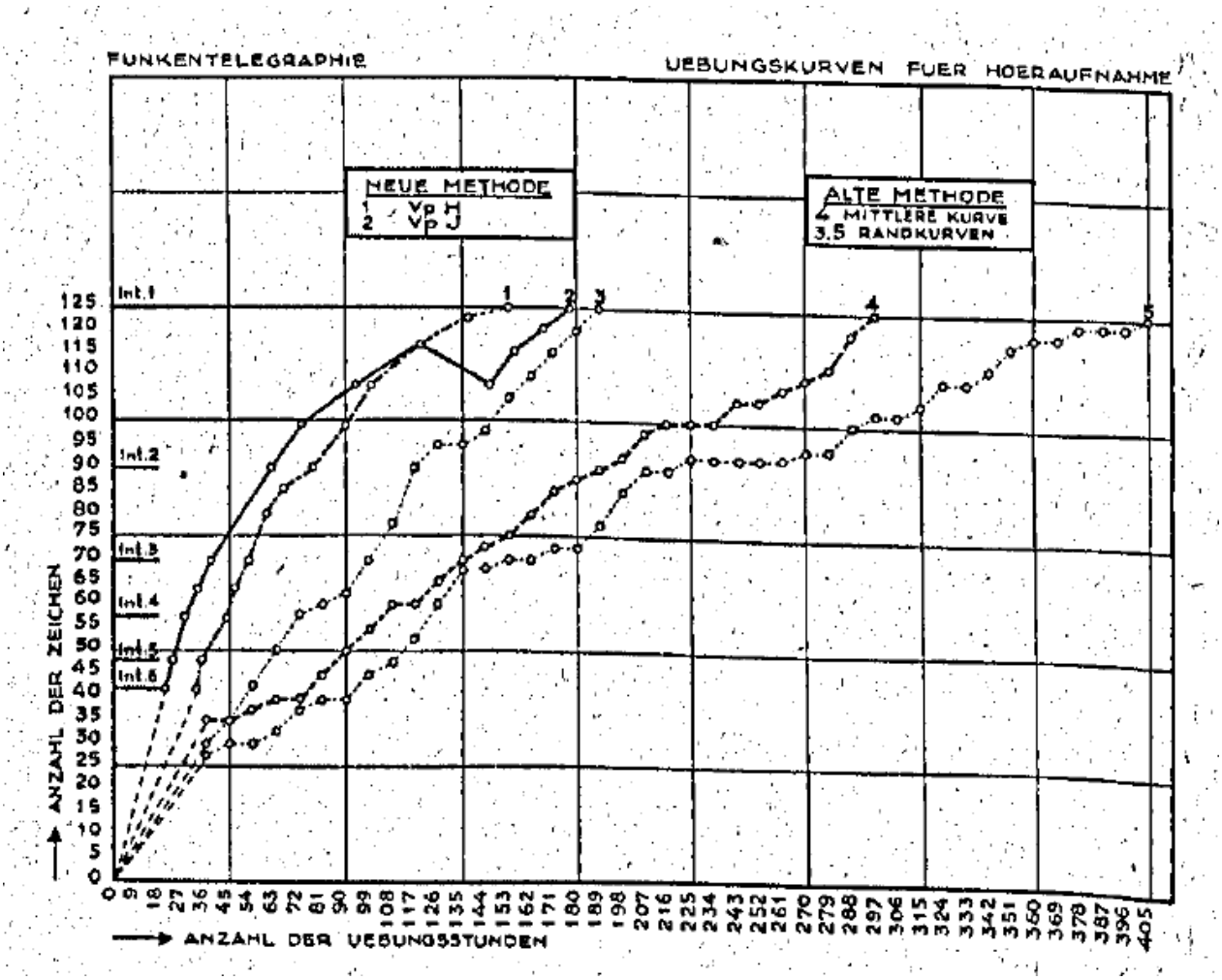

Fig. 1 Morse code reception speed [CpM] vs number of training hours
curves 3..5: subjects trained with old training method
curves 1 and 2: two subjects ['H' and 'J'] trained with new method
[from original publication, page 148]

The results are so far very satisfying, but experiments on a larger scale are certainly desirable. Unfortunately, I cannot perform such experiments right now, as for the time being no new telegraphists will be employed by the P.T.T. service in the Netherlands. Incidentally, I intend to do a training experiment with the outlined new method, that includes all 62 characters required by international agreements for radio operators. I guess that training these 62 characters by using my new method will not take significantly longer than training 40 characters only.

For colleagues in other countries, which would like to experiment with the new method, I am gladly available with the collected experience. And I would be very thankful to receive experimental data for training of 62 characters with the old method.

(1) Biegel, R.A.: Eine Eignungsprüfung für Funkentelegraphisten
[A Qualifying Examination for Radio Telegraphists],
Psychotechnische Zeitschrift, Vol 6 (1931), No 2, pp 41-45

[Additional detailed explanation:

Biegel seems to use a Creed Morse Transmitter that is driven by a punched paper tape. This tape is punched in a way that was probably first described for the Wheatstone automatic Morse system.

See e.g.: https://en.wikipedia.org/wiki/Wheatstone_system

On this paper tape there are three rows of holes. The middle row has a constant perforation of 10 holes per inch, so that a star wheel can move the paper forward. The distance between the holes is called “Rev”, because this distance is linked to one reversal of current in the sensing system. This distance corresponds to two basic Morse code elements. A simple example is shown in the following Fig. 2:

Fig. 2 Piece of Wheatstone/Creed paper tape carrying the letters “QST”

It can easily be seen, that a “dit” is coded with a hole in the top row and a hole in the bottom row. This covers two elements: the dit itself and the following inter-element space. A “dah” is coded with a hole in the top row and a hole in the bottom row of the following Rev, thereby covering 2 elements of the dah in the first Rev, and then the 3rd element of the dah and the following inter-element space in the second Rev. An inter-character space is coded by a Rev without further holes, thereby adding another 2 elements of space, giving a total inter-character space of 3 elements.

Now the characters on the paper strip in the following Fig. 3 can easily be decoded, and it can be seen that the inter-word space consists of 3 additional Rev, which leads to a total inter-word space of 7 elements.

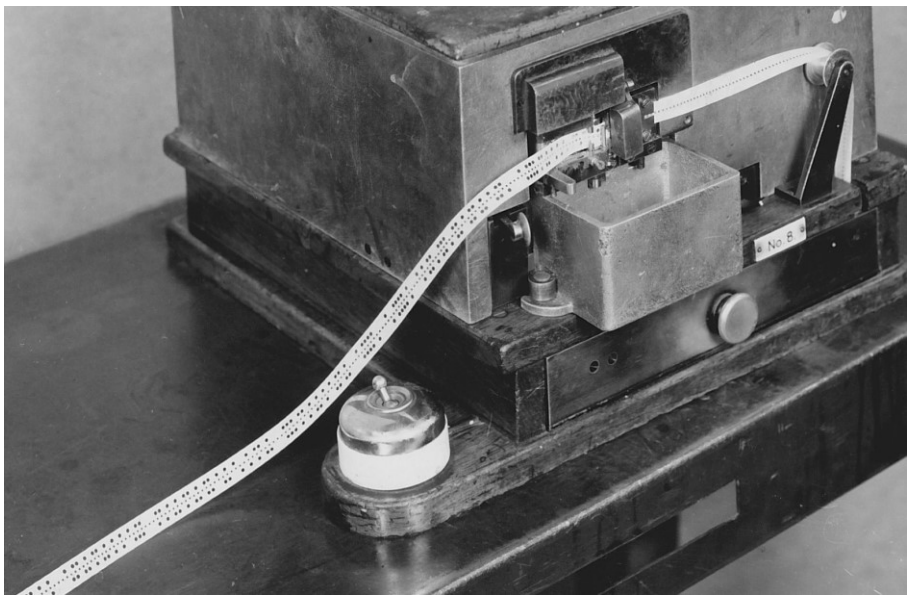

Fig. 3 Paper tape in a Regenerator-Perforator
“CREED PRINTER SPEC – THE QUICK BRO”

(from the website of the Electra House Retired Colleagues Association, www.ehrca.co.uk)

When such a paper tape is run at a speed of 160 cm/min (63 inch/min), then Biegel gives 632 Rev/min and a duration of 0.095 sec per Rev. It then follows that a single element of Morse code takes 0.0476 sec, and this again corresponds (with some generous rounding) to a standard Morse speed of 125 CpM or 25 WpM.

(see e.g.: John Bloom, A Standard For Morse Timing, ARRL Lab., QEX April 1990)

The following may help to understand Biegel's calculations:

At 125 CpM, there will be 125 inter-character spaces within 60 seconds of code. Each of these spaces consumes 3/2 Rev or 3/2 x 0.095 sec = 0.14 sec. And all 125 spaces together consume 17.5 seconds. This leaves 42.5 seconds for the 125 bare characters, without the space at the end. On the average that amounts to 0.34 seconds per bare character.

For the "Old Method", the tape speed is simply slowed down. At half the speed (80 cm/min or 31.5 inch/min) the average length of a bare character is doubled to 0.68 seconds, and the inter-character space is also doubled to 0.28 seconds. This leaves room for 62.5 characters within 60 seconds. That's 62.5 CpM or half of 125 CpM, as expected.

For the "New Method", the tape speed is not changed, but additional blank spaces are entered between the characters. A single blank space corresponds to 2 Rev on the tape, which consume 0.19 seconds. So, for e.g. "Interval 3" (indicating standard space plus 2 additional blank spaces), the inter-character space is increased from 0.14 sec to 0.14 + (2 x 0.19) = 0.52 sec. Adding the average length of a bare character gives 0.86 sec for the average character including the inter-character space. And that leaves room for 70 characters within 60 seconds, a speed of 70 CpM or 14 WpM. The values for the other "Interval" cases can be calculated accordingly.

Biegel indicates, that she would have liked to include an intermediate "Interval 1 ½" case. It is easy to see that this could have been accomplished by adding a single "Rev" space between the characters. That would have extended the duration of the inter-character space from 0.14 sec to 0.235 sec, giving an average character length of 0.34 + 0.235 = 0.575 sec or 104 characters in 60 seconds.

It can be assumed that a typewriter-printer for Morse tapes just shifted the tape by 2 Rev, when the spacebar was pressed. And, as indicated in Biegel's paper, a shift of just 1 Rev should have been possible.

End of detailed explanation]