HANDBOOK OF ELECTROENCEPHALOGRAPHY AND CLINICAL NEUROPHYSIOLOGY

EDITOR-IN-CHIEF A. REMOND

VOLUME 3

Techniques and Methods of Data Acquisition of EEG and EMG

EDITOR: M. R. DeLUCCHI

The University of Texas Health Science Center at Houston, Texas (U.S.A.)

PART B

Graphic and Magnetic-Tape Recording of Bioelectrical Phenomena

EDITORS: J. D. FROST JR. AND J. S. BARLOW

Baylor College of Medicine, Houston, Texas (U.S.A.) and Massachusetts General Hospital, Boston, Mass. (U.S.A.)

ELSEVIER

HANDBOOK OF ELECTROENCEPHALOGRAPHY AND CLINICAL NEUROPHYSIOLOGY

Editor-in-Chief: **Antoine Rémond**
Centre National de la Recherche Scientifique, Paris (France)

VOLUME 3

Techniques and Methods of Data Acquisition of EEG and EMG

Editor: **M. R. DeLucchi**
The University of Texas Health Science Center at Houston, Texas (U.S.A.)

PART B

Graphic and Magnetic-Tape Recording of Bioelectrical Phenomena

Editors: **J. D. Frost Jr. and J. S. Barlow**
Baylor College of Medicine, Houston, Texas (U.S.A.) and Massachusetts General Hospital, Boston, Mass. (U.S.A.)

Elsevier Scientific Publishing Company – Amsterdam – The Netherlands

International Federation of Societies for EEG and Clinical Neurophysiology

HANDBOOK EDITORIAL COMMITTEE

ANTOINE RÉMOND
Centre National de la Recherche Scientifique,
Paris (France)

C. AJMONE MARSAN
National Institute of Neurological Diseases and Stroke,
Bethesda, Md. (U.S.A.)

M. A. B. BRAZIER
Brain Research Institute,
University of California Medical Center,
Los Angeles, Calif. (U.S.A.)

F. BUCHTHAL
Institute of Neurophysiology,
University of Copenhagen,
Copenhagen (Denmark)

W. A. COBB
The National Hospital,
London (Great Britain)

ISBN 0-444-41423-1

Copyright © 1976 by Elsevier Scientific Publishing Company, Amsterdam
All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of the publisher.

Elsevier Scientific Publishing Company, Jan van Galenstraat 335, Amsterdam
Printed in The Netherlands

Sole distributor for Japan:
Igaku Shoin Ltd.
5-29-11 Hongo Bunkyo-ku
Tokyo

All other countries:
Elsevier Scientific Publishing Company
Amsterdam, The Netherlands

International Federation of Societies for EEG and Clinical Neurophysiology

HANDBOOK EDITORIAL COMMITTEE

ANTOINE RÉMOND
Centre National de la Recherche Scientifique,
Paris (France)

C. AJMONE MARSAN
National Institute of Neurological Diseases and Stroke,
Bethesda, Md. (U.S.A.)

M. A. B. BRAZIER
Brain Research Institute,
University of California Medical Center,
Los Angeles, Calif. (U.S.A.)

F. BUCHTHAL
Institute of Neurophysiology,
University of Copenhagen,
Copenhagen (Denmark)

W. A. COBB
The National Hospital,
London (Great Britain)

A great need has long been felt for a Handbook giving a complete picture of the present-day knowledge on the electrical activity of the nervous system.

The International Federation of Societies for EEG and Clinical Neurophysiology is happy to be able to present such a Handbook, of which this is a small part.

The decision to prepare this work was made formally by the Federation at its VIIth International Congress. Since then nearly two hundred specialists from all over the world have collaborated in writing the Handbook, each part being prepared jointly by a team of writers.

The Handbook begins with an appraisal of 40 years of achievements by pioneers in these fields and an evaluation of the current use and future perspectives of EEG and EMG. The work subsequently progresses through a wide variety of topics—for example, an analysis of the basic principles of the electrogenesis of the nervous system; a critical review of techniques and methods, including data processing; a description of the normal EEG from birth to death, with special consideration of the effect of physiological and metabolic variables and of the changes relative to brain function and the individual's behaviour in his environment. Finally, a large clinical section covering the electrical abnormalities in various diseases is introduced by a study of electrographic semeiology and of the rules of diagnostic interpretation.

The Handbook will be published in 16 volumes comprising 40 parts (about 2500 pages altogether). For speed of publication most of the 40 parts will be published separately and in random order.

ISBN 0-444-41423-1

Copyright © 1976 by Elsevier Scientific Publishing Company, Amsterdam
All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of the publisher,

Elsevier Scientific Publishing Company, Jan van Galenstraat 335, Amsterdam
Printed in The Netherlands

Sole distributor for Japan:
Igaku Shoin Ltd.
5-29-11 Hongo Bunkyo-ku
Tokyo

All other countries:
Elsevier Scientific Publishing Company
Amsterdam, The Netherlands

PART B

GRAPHIC AND MAGNETIC-TAPE RECORDING OF BIOELECTRICAL PHENOMENA

Editors: **J. D. Frost Jr. and J. S. Barlow**
Baylor College of Medicine, Houston, Texas (U.S.A.) and Massachusetts General Hospital, Boston, Mass. (U.S.A.)

Collaborators:

J. S. Barlow, *Massachusetts General Hospital, Boston, Mass. (U.S.A.)*

J. D. Frost Jr., *Baylor College of Medicine, Houston, Texas (U.S.A.)*

R. M. Harper, *Brain Research Institute, University of California, Los Angeles, Calif. (U.S.A.)*

此为试读，需要完整PDF请访问：www.ertongbook.com

Preface

The recording of bioelectrical phenomena has extended appreciably beyond the domain of the simple graphic write-out onto moving photographically sensitive paper or as an ink tracing or its equivalent. Thus, simultaneously with the graphic write-out, recordings may be made on magnetic tape, or the bioelectrical signal may be led into telephone lines for recording elsewhere or may be fed directly into computers. Contemporary devices for recording bioelectrical phenomena must therefore meet not only the requirements for satisfactory graphic recording itself but also those for adequate and convenient transfer of the signals of the bioelectrical phenomena to and from auxiliary equipment. At the same time, the increasing use of such auxiliary equipment in conjunction with clinical electroencephalography promises to have a major impact on the latter. It is in the context of these recent developments, as well as additional ones on the horizon, that this Part on graphic (sometimes termed direct) recording and magnetic-tape (sometimes termed indirect) recording is presented.

Introduction

In the previous Part of this Volume (Part A: Acquisition of Bioelectrical Data: Collection and Amplification), questions of electrodes and electrode placement, preamplification and amplification in electroencephalographs, together with general specifications, have been considered. In the present part of Volume 3 (complementary to the preceding one), the write-out of EEG data as a graphic record, write-out on magnetic tape, and telephone transmission of EEGs are considered. The next part of this Volume begins the consideration of the graphic recording itself (Part C: Traditional Methods of Examination in Clinical EEG), whereas Volumes 4 and 5 consider the computer evaluation of bioelectrical data.

In the present Part, the Section on graphic recording is primarily oriented toward pen-and-ink recording, including consideration of selection of inks and paper for the graphic recordings. Some general specifications on instrumentation are discussed, particular emphasis being laid on the compatibility of input/output connections of the electroencephalograph with ancillary equipment such as tape recorders, etc. The recommendations of the EEG Instrumentation Standards Committee of the International Federation of Societies for Electroencephalography and Clinical Neurophysiology are included as an Appendix.

Methods of EEG storage (archiving) for clinical and computer-analysis purposes are discussed, including retention of the original record, microfilm, and the possibility of magnetic-tape-cassette storage. Optical scanning techniques, which make possible the reconversion of a graphic record to electrical form for transfer to magnetic tape, computer data processing, etc., are considered.

The Section on magnetic-tape recording gives prime consideration to a frequency response sufficiently low (effectively, to DC) for electroencephalograms; this is most often achieved by frequency-modulation (FM) techniques, but not exclusively so.

Certain aspects of telephone transmission of EEGs are discussed, in particular the limitations that present-day telephone lines impose on the upper frequency response of such systems, and their implications when, for example, eight channels of EEG data are transmitted.

Section I. Graphic Recording

The usefulness and value of clinical electroencephalography is currently based upon the ability of trained observers to detect specific patterns of brain electrical activity as they occur over time. Consequently, the basic function of an electroencephalograph is to present the cerebral electrical patterns in an optimal form for observation by the human sensory apparatus. A survey of the history of electroencephalography reveals a great variety of proposed display schemes, ranging from the simple to the almost incomprehensibly complex. Most are based upon some form of visual presentation, but a few schemes based upon audio methods have been proposed. In spite of this constant search for a better way, at the present time essentially all useful information is derived from simple, multichannel plots of voltage *versus* time in basically the same manner as that used by Berger (1929) in his original observations of the electroencephalogram of man.

Most methods of producing a tracing showing voltage over time have been based upon the galvanometer principle; the most familiar example is the ink-writing pen recorder that generates a continuous paper write-out. Closely related methods that employ the principle of the galvanometer include the high-pressure ink jet, the heated stylus in conjunction with heat-sensitive paper, and photo-optical techniques (*e.g.*, employing ultraviolet-sensitive paper). Although other methods are in use, such as those based upon the cathode-ray tube and the more recent electrostatic techniques, this discussion is directed toward the galvanometric methods because of their extensive use in clinical electroencephalography.

While the electroencephalographer needs little knowledge of the engineering aspects of graphic-recorder design, he should be aware of the general principles involved and of their limitations, for example, the possible distortion in data displayed.

A. DESIGN FACTORS

1. Galvanometers

A galvanometer, as currently used, consists basically of a coil of wire suspended in the field of a permanent magnet. A current passed through the coil generates a second magnetic field that interacts with the field of the permanent magnet, resulting in movement of the coil about its pivot points to an equilibrium position determined by the current strength and by the stiffness of the restoring spring or torsion bar. In an electroencephalograph the final stage of the amplification system, *i.e.*, the power amplifier, supplies the current for the coil, the current being proportional, in turn, to the voltage or potential difference at an electrode pair on the scalp. The angular motion (rotation) of the coil drives an attached pen arm which, in turn, traces a representation of the pen motion on the moving chart paper, as depicted in Fig. 1.

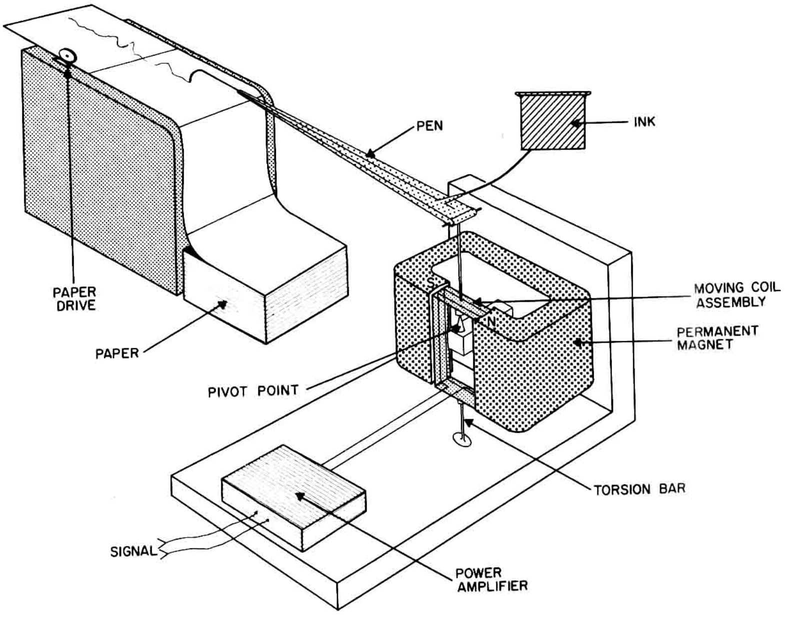

Fig. 1. Diagram of a moving-coil-type galvanometer.

An ideal galvanometer produces a deflection whose magnitude is exactly proportional to the magnitude of the current, thereby providing a convenient means for monitoring or measuring the characteristics of the current. How faithfully the galvanometer motion follows the electrical-potential difference at the recording site will consequently depend upon the characteristics of the electrodes and the amplifiers, as well as on the galvanometer write-out system itself.

2. Pen damping

As might be expected, there are several pitfalls inherent in the scheme illustrated in Fig. 1. As a result of the interaction of the restoring spring and the mass of the pen components, the system shown in this figure tends to be naturally oscillatory, or resonant, to some degree. As illustrated in Fig. 2, *C*, the actual output of such a device when presented with a step change in input voltage, or current (Fig. 2, *A*), is not the ideal representation (Fig. 2, *B*) but rather a series of oscillations that eventually settle to a new steady-state position.

Oscillations that decrease in amplitude over time after a transient deflection, as do those of Fig. 2, *C*, are referred to as "damped oscillations" and reflect the rate at which the kinetic energy imparted to the resonant system is dissipated. In the case of the minimally damped example of Fig. 2, *C*, this energy dissipation is relatively slow and is largely dependent upon friction at the pivot points and at the pen-to-paper interface and, to a small extent, upon air resistance of the moving coil and pen assembly.

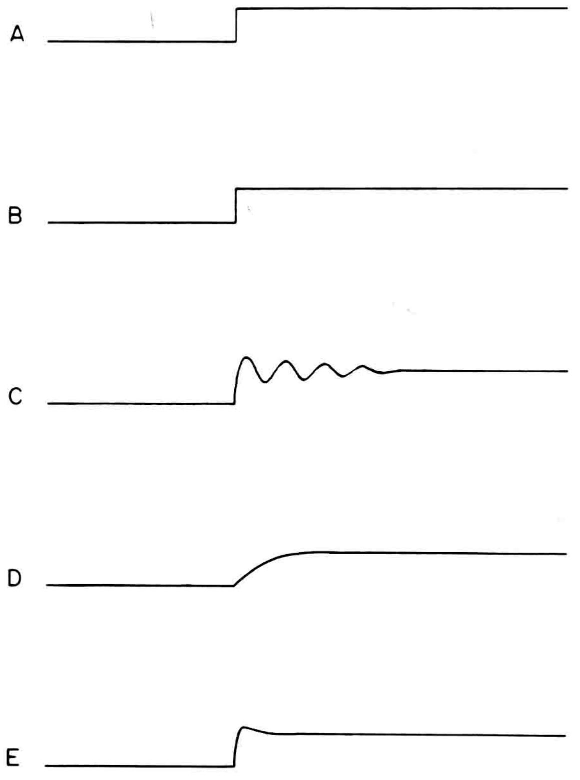

Fig. 2. Example of outputs from a galvanometer such as that shown in Fig. 1. *A*: A step change in current through coil assembly. *B*: The ideal graphic representation. *C*: The actual output of the device (undamped). *D*: Overdamped output. *E*: Critically damped output.

If damping is greatly increased, as, for example, by suspending the coil assembly in a viscous fluid or by electronic means (see below), the output would appear similar to the example of Fig. 2, *D*. No oscillation occurs in response to the transient input voltage change, and instead the pen rises relatively slowly to its new level. This overdamped situation results in severe distortion of the signal, especially in the case of high frequencies, and is just as undesirable as the underdamped condition.

If the damping factors are adjusted to be intermediate between overdamping and underdamping, the system is "critically damped" and will provide the most faithful transient response possible with minimal overshoot. As illustrated in the example (Fig. 2, *E*), some distortion remains, but with proper design this will be minimal

此为试读，需要完整PDF请访问：www.ertongbook.com

over the frequency range for which the recorder is intended.

In most modern electroencephalographs, damping forces inherent in the galvanometer and pen assembly, including the frictional contact between pen tip and paper, leave the system somewhat underdamped. Critical damping is then achieved and adjusted electronically. Although the techniques utilized by various manufacturers vary, in general the process may be considered as a form of negative feedback in which a voltage proportional to the velocity of the moving galvanometer coil is applied, in an inhibitory fashion, to the input of the power amplifier. A given coil velocity, then, automatically results in a proportional reduction in driving force supplied to the coil. Such a signal, proportional to coil velocity, may be obtained in various ways. For example, in one widely used instrument, the back electromotive force (emf) generated by the coil as it moves in the magnetic field is sensed by a bridge circuit of which the coil forms one leg. The amount of back emf utilized for damping is easily controlled by a potentiometer; thus, critical damping may be readily adjusted. Additional resistive and capacitive elements may be placed in the feedback circuits to improve selectively the high-frequency response of the system above the resonant frequency of the galvanometer.

3. Vertical-axis display

Another major source of distortion in the conventional galvanometer system (shown in Fig. 1) arises from the method used to transform the rotary motion of the coil into a representation of the vertical amplitude-coordinate. The origin of this distortion is represented in Fig. 3; a curvilinear output results as a consequence of

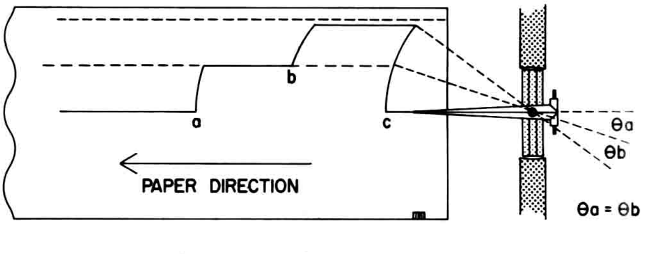

Fig. 3. Sources of time and amplitude errors in a curvilinear system. *a* and *b*: Different vertical (amplitude) deflections produced by equal angular rotations of the penshaft (*θa* and *θb*). *c*: Source of time (horizontal) axis distortion.

the arc described by the radius of the pen arm in response to the rotary motion of the galvanometer coil to which it is attached. As depicted in Fig. 4, the actual output from such a system (*C*) differs from the ideal output (*B*) in response to a test input signal (*A*) both in amplitude and in time (*i.e.*, vertically and horizontally on the paper). Thus, the increment of true vertical deflection at point *a* (in Fig. 3 and 4, *C*) is greater than the incremental deflection at point *b* in Fig. 3 and 4, *C*, although the input voltage increment was identical in the two instances; the actual amplitude response is therefore nonlinear.

The time distortion, or delay, introduced by the curvilinear write-out is apparent from inspection of point *c* in Fig. 3 and 4, *C*. In the case of a typical machine with 11.4 cm ($4\frac{1}{2}$ in.) pens and a paper speed of 30 mm/sec, at a 1.5 cm vertical deflection the tip of the pen writes on the paper an apparent 67 msec later than at a zero vertical deflection. Longer pens will reduce this error, while shorter ones will magnify it. The amount of this time distortion also varies nonlinearly with deflection, becoming increasingly great for increasingly larger deflections of the pens.

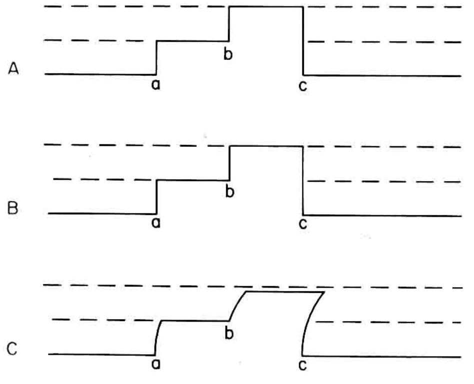

Fig. 4. Vertical-axis-display distortion in a curvilinear system. *A*: Test input signal. *B*: Ideal representation. *C*: Actual output.

In practice, the amplitude nonlinearity described above is so slight under typical operating conditions (*e.g.*, for 10.2 or 12.7 cm (4 or 5 in.) pens and 3 cm maximal vertical deflections) that its effect is not readily measurable, and consequently it can usually be ignored. The user should be aware, however, of the possibility of more significant distortions when the amplitudes recorded are unusually great.

The time-distortion problem is of more significance in clinical EEG, since its effects are readily apparent even to the unaided eye. Thus, for example, precise timing of events in adjacent channels is cumbersome if the events are of different amplitudes. The overall appearance of the record is modified by curvilinearity, and the judgment concerning rise time of specific events is made especially difficult. The problem is compounded if the observer must interpret records from a variety of different machines whose pen lengths vary.

Because of these problems, several techniques have been devised to convert the curvilinear write-out to rectilinear coordinates, although these techniques necessarily entail greater complexity. A mechanical linkage equivalent in basic principle to that illustrated in Fig. 5 is available as an option on several commercial EEG machines and effectively converts the rotary motion of the galvanometer coil to a reasonably true vertical amplitude representation. The ink-writing pen tip slides vertically upon a fixed shaft suspended above the writing surface. A small pin protruding from the upper surface of the sliding pen assembly fits into an elongated slot on the terminal portion of the galvanometer arm. As the arm moves in an arc,

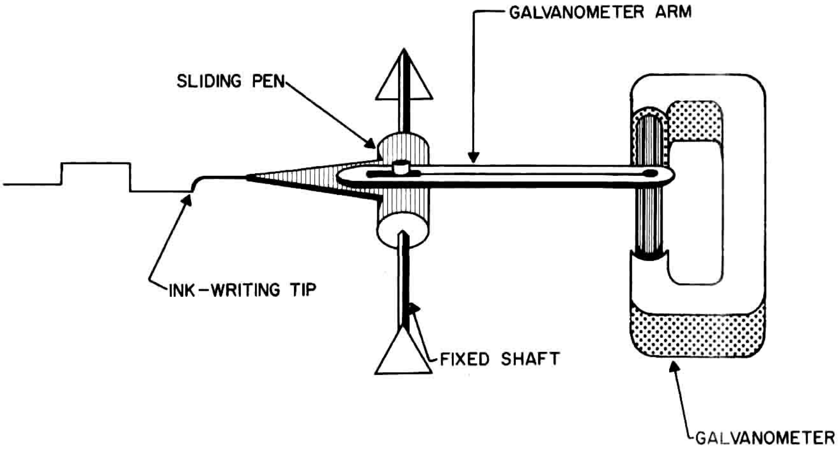

Fig. 5. A mechanical linkage to convert the output to rectilinear coordinates.

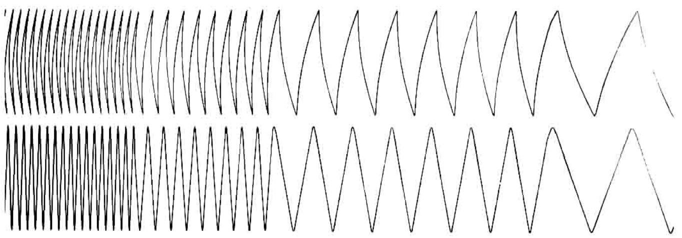

Fig. 6. Comparison of curvilinear (*top trace*) and rectilinear (*bottom trace*) write-outs of a triangular wave at four different paper speeds (note the last change of paper speed just before the peak of the curves). Original peak-to-peak deflection: 4.5 cm; length of pen for curvilinear write-out: 12.7 cm.

a true vertical motion is imparted to the ink-writing pen, thereby effectively removing the curvilinear distortion and eliminating the aforementioned time distortion. The small nonlinearity in amplitude mentioned previously is appreciably reduced in this scheme and hence does not pose significant problems.

Actual conversion of a curvilinear write-out to a rectilinear one is illustrated in Fig. 6.

4. Pen alignment

When pen-writer units are used in multichannel arrays, as they routinely are in electroencephalography, the possibility of small individual variations in stylus length or horizontal alignment presents a potential source of time-axis distortion. If one pen tip leads or lags another, a fixed time error is introduced; if not recognized, it may be misinterpreted as a physiological phenomenon by the observer. Pen alignment is easily adjusted in most commercial instruments and is readily checked by applying a calibration signal simultaneously to all channels and observing the relationship of the deflections to the vertical grid lines on the paper.

If curvilinear pens are used, care must be taken during this adjustment procedure to insure that all pens are centered properly, since, as noted previously, curvilinearity also introduces a time-axis distortion.

5. Paper-drive mechanism

The paper-drive mechanism of the recorder is a usually neglected aspect but one which potentially can introduce serious errors. Since all judgments regarding time (and hence all judgments regarding frequency, duration, rise-time, etc.) depend upon an accurate and constant flow of paper past the pen tips, the user must occasionally confirm that this is, in fact, the case. This is particularly important in laboratories where several machines are used and the possibility exists that a follow-up or repeat study might be performed on a different instrument. In these instances, a relatively minor, undetected difference in paper speed between machines would be interpreted as a change in EEG frequency.

Wave-form distortion can occur if variations in paper speed are present. For example, sporadic pauses or hesitations in paper flow sometimes occur when the drive mechanism is improperly adjusted (or when paper is loaded improperly or is of the wrong size). These brief pauses can convert normal wave forms into spike-like forms that conceivably could be misinterpreted as abnormalities.

Paper speed and constancy should be checked periodically by applying a test signal of known frequency and wave form to the inputs of all channels simultaneously and carefully observing the graphic record for frequency and wave-form distortion. A time-marker channel provides a convenient way in which to monitor this variable continuously, since a distortion due to changes in paper speed would be reflected in this channel as well.

6. Number of channels and mechanical specifications

Currently (the mid 1970's), a minimum of 8 channels of graphic recording is used customarily for clinical electroencephalography. Except for portable recording, in which the electroencephalograph is taken to the patient's bedside, 16 channels are most frequently recorded in EEG laboratories, at least in the larger centers.

For easy interchange of machines when necessary and for facilitation of maintenance, all electroencephalographs should be readily movable (*i.e.*, on casters or rollers).

Detailed mechanical and other specifications suggested by the Committee on EEG Instrumentation Standards of the International Federation of Societies for Electroencephalography and Clinical Neurophysiology are included in the Appendix.

B. SELECTION OF EEG PAPER AND INK

The following considerations concern primarily paper for ink-written EEGs, although the comments will, in general, also pertain to other types of recordings (*e.g.*, to heat-sensitive paper).

Considerations affecting the choice of paper include: (1) the extent of time the recording is to be kept; and (2) whether quantitative measurements are to be made directly from the graphic recording.

The quality of paper used for temporarily stored EEGs obviously need not be the same as that for records to be retained for an extended period. Nonetheless, in almost every clinical laboratory, selected records are retained for varying periods; hence, at least reasonably good quality paper (allowing only minimal blotting or spreading of the ink) is desirable.

Background grid lines on the paper are an important consideration. It is very convenient, if not essential, to have vertical lines on the paper indicating seconds and fractions thereof. Thus, a widely used convention consists of major divisions every 1 sec, with minor markings every 200 msec. The actual line spacing is, of course, determined by the paper speed, usually $1\frac{1}{2}$ cm/sec or 3 cm/sec. Less important, although convenient for some purposes, are horizontal lines (*e.g.*, minor divisions at intervals of 2 or 5 mm and major divisions at 1 cm intervals), which can be used not only for amplitude calibration but also for setting the baseline positions of the write-out pens. The latter procedure assumes increased importance if the ink-written record serves as a monitor for the EEG input to, or output from, other systems (*e.g.*, for recording on magnetic tape or for telephone transmission), since an inadvertent baseline offset diminishes the available dynamic range (maximum distortionless peak-to-peak excursion) of such systems.

Sequentially numbered pages (at least to 1000 in a given pack) facilitate the subsequent identification of particular features of a given EEG. Some institutions also imprint their name and a diagram of electrode placements on each page.

Care should be exercised in selecting the ink color for the EEG pens and the color of the background grid lines and any other information imprinted on the paper (*e.g.*, page numbers, diagram of electrode placement, name of institution). Inks that readily fade with exposure to light should be avoided. The ink used for the EEG itself should photograph well. It should be possible, by appropriate filtering, to eliminate the background imprint during photography, since EEGs are ordinarily published without any background.

There are additional requirements on the ink color and the color of the imprinted-background on the paper if any recordings are to be subjected to automatic photo-optical scanning (see subsequent Section). The scanning pens of such devices require that recordings be done in black ink on paper with a colored background imprint (red being the most satisfactory) to which the photo-optical system is relatively insensitive.

If the original graphic recordings are retained only temporarily, an appreciable saving in paper can be attained by using both sides, although the convenience of a background grid and of page numbering is lost. (The additional expense of printing the background grid on both sides of the paper defeats the economic saving in using both sides of the paper.)

Section II. Storage (Archiving) and Retrieval of EEG Recordings

Retention of the original graphic recording for archival purposes is obviously the most convenient method of storing, or archiving, records, but this method rapidly becomes impractical if large numbers of EEGs are recorded in a laboratory.

A. MICROFILM

Continuous-flow microfilming provides a convenient method to store compactly EEG recordings, which can be viewed on a microfilm reader, enlarged to approximately the original size. Some microfilm readers can further enlarge a selected area on the microfilm for viewing. Microfilm can currently be stored on cartridges or on reels, the cartridges taking up somewhat more space. For viewing purposes, the film advance should be electrically controlled and continuously variable in speed, since manually advanced film is generally too irregular in its speed for convenient viewing. The microfilm record should include all pertinent data for the EEG (original request, preliminary interpretation, final interpretation, etc.). It may also be desirable to include full specifications of the linkages or montages for each run.

By means of continuous electrostatic printing, a complete reproduction of the original EEG can be obtained from the microfilm.

B. MAGNETIC TAPE

Until relatively recently, commercially available magnetic-tape recorders having the necessary low-frequency response required for EEGs have been of an instrumentation grade. They had relatively high mechanical and electrical specifications and were designed for purposes (*e.g.*, recording missile-range data) other than electroencephalography (see Section V). Thus, except for specially modified instruments, the frequency range of such recorders has been much greater than required for clinical electroencephalography; at the same time, the grouping of channels (7, 14 or 28 channels) has not been compatible with the usual clinical electroencephalographic specification of 8 or 16 channels. Although quite recently there have been some specially designed recorders compatible with electroencephalographic needs in terms of channels, they have also been of an instrumentation grade and therefore relatively expensive. Consequently, the routine tape storage of all clinical EEGs (even were it desirable) has, in the past, been totally unfeasible.

Somewhat less expensive, reel-to-reel tape recorders with DC response have

此为试读，需要完整PDF请访问：www.ertongbook.com