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Journée, H. L.; van Manen, Jan; van der Meer, Joop J.

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Demodulation of e.m.g.s of pathological tremours. Development and testing of a demodulator for clinical use

H. L. Journée

Department of Neurosurgery, State University, Oostersingel 59, 9713 EZ Gröningen, The Netherlands

J. van Manen

Wilhelmina Gasthuis, 1e Helmersstraat 104, 1054 EG Amsterdam, The Netherlands

J. J. van der Meer

Department of Neurosurgery, State University, Oostersingel 59, 9713 EZ Gröningen, The Netherlands

Abstract—*In clinical tremour recordings, e.m.g. signals allow highly localised recordings to be made. This is in contrast to mechanical recordings which have been used extensively in the past. E.m.g. recordings make it possible to distinguish between tremours in agonist and antagonist muscle groups. E.m.g. signals, however, have poor signal-to-noise characteristics. In this study the e.m.g. of pathological tremours is considered as amplitude-modulated noise. The design of a demodulator and some tests of its performance are described. The visual detectability of an undemodulated tremour e.m.g., when written on a polygraphic recorder, is expressed as a modulation depth, and is about 60%. This improves after demodulation to a level of 20%. The placement of the electrodes and filtering of the e.m.g. signal will influence the shape of the power spectrum of the e.m.g. itself. However, these factors do not critically influence the demodulated tremour e.m.g. For this reason also a demodulator is a useful instrument for recording clinical tremours.*

Keywords—*Demodulator, Electromyography, Tremours*

1 Introduction

A TREMOUR can be considered as a sequence of involuntary, purposeless, oscillatory movements of one or more parts of the body as a result of skeletal muscular activity (MARSHALL, 1968; BRUMLIK and YAP, 1969; BRUMLIK and MEANS, 1969; MORGAN *et al.*, 1975; SÄLTZER, 1975). Recordings of tremours have been performed since the end of the last century with the clinical aim of classifying a tremour objectively for descriptive purposes. The first measurements started with Marey's 'tambour à reaction' in 1890 (in PELNÁR, 1913) and involved direct, mechanical measurement of the tremour. SCHWABB and COBB (1939) and JUNG (1941) were among the first to describe e.m.g. recordings in which pathological tremours can be recognised. Despite poor spatial resolution, which causes several groups of muscles in different parts of the body to contribute to the mechanogram, this form of recording is still used widely in clinical practice.

E.m.g. signals can record a tremour directly in one muscle or muscle group. However, if the raw e.m.g. signal is written out on a polygraphic recorder the nature of the signal, which may be regarded as amplitude-modulated noise (SHWEDYK *et al.*, 1977), makes it barely possible to recognise the tremour by visual inspection. This makes the e.m.g. less popular in the use of tremour recordings. It is therefore necessary to demodulate a tremour e.m.g. in order to derive the tremour signal itself (on which demodulation noise is now also superimposed). In this paper we will describe the spatial resolution of surface e.m.g. recordings, the crosstalk between agonists and antagonists in the forearm and the spectral properties of the carrier noise of the amplitude modulated signal. The design and testing of a demodulator that has been developed for recording pathological tremours is also described.

2 Description of the tremour e.m.g.

According to KREIFELDT (1969) and SHWEDYK *et al.* (1977) the function of the force developed by a muscle in time can be recognised in the e.m.g. of this

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muscle as amplitude-modulated noise. The carrying noise can also be seen in the e.m.g. of a stationary contracted muscle of a normal subject. Patients with pathological tremours have physiologically normally functioning muscles. We shall therefore use the signal properties of the e.m.g. of isometrically contracting muscles of normal subjects for the description of amplitude modulation.

The distance between the electrodes and the different muscle fibres plays an important role in the power spectra of the e.m.g.s. Calculations by LINDSTRÖM (1970, 1973) show that higher frequencies become more attenuated relative to lower frequencies as this distance decreases. From this one can expect the high frequencies seen in the power spectrum to be generated in muscle fibres immediately underlying the electrodes and the lower frequencies to arise also from deeper lying muscle fibres. According to measurements by SATO (1976, 1977) the power spectrum of an e.m.g. of stationary nonfatigued, isometrically contracting muscles does not depend on the force and is time invariant. If one assumes that the middle of a muscle is separated by approximately 5 mm from the surface electrode it is possible to bring the results of the calculations of Lindström into acceptable agreement with the spectra of SATO (1976*a*, *b*), in which nearly all the power is present between 0 and 150 Hz. The area under the power spectrum, being equal to the variance of the e.m.g. signal (Parceval's theorem), increases progressively with the muscular force. This means that a uniform increase is seen in every part of the power spectrum without a change in its shape. Hereby one can conclude that it is appropriate to filter the e.m.g. signal prior to the demodulation. The time invariance extends to a period of at least some weeks (SATO, 1976*b*). When a muscle becomes fatigued the shape of the power spectrum changes slowly, so that an increase of power in the low-frequency band up to 40 Hz is seen (KWATNY *et al.*, 1970; SATO, 1977).

The crosstalk between muscles of the flexor group and the extensor groups in the forearm is considered as a measure of the selectivity of e.m.g.s. The minimum distance between the muscle fibres in the flexor group and the electrodes above the extensors varies from approximately 30 to 60 mm, depending on the patient, whereas this minimum distance between muscle fibres of the extensors and the same electrodes is only a few millimetres. From LINDSTRÖM's (1973) calculations combined with SATO's e.m.g. power spectra (1976*a*, *b*, 1977), one can expect a minimum crosstalk of approximately 30 dB. We have been able to confirm this in experiments on healthy subjects during maximal flexion and extension of the hand. During maximal flexion the e.m.g. signal from the surface electrodes above the extensors was at least 31 dB smaller than that during maximal extension. When considering the e.m.g. from the flexors the corresponding ratio was 36 dB. In practical situations this crosstalk can be seen in some pathological tremour e.m.g.s. These are reported by CALNE and LADER (1969) and called minor waves. They can sometimes be seen as small e.m.g. bursts in the silent periods between two subsequent large e.m.g. bursts in tremours where agonist and antagonist muscle groups show an alternating contraction pattern. In an illustration of e.m.g.s, Fig. 1*a* shows the e.m.g. during stationary isometric contraction whereas Fig. 1*b* is the e.m.g. of the extensor group in the forearm of a patient with Parkinson's disease during a resting tremour.

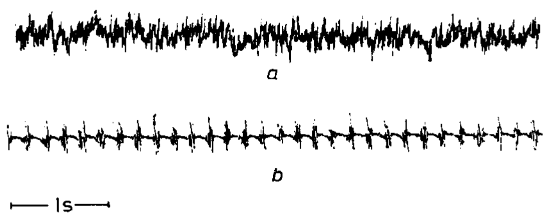

Fig. 1 (*a*) *E.m.g. of the extensor muscle group in the forearm of a healthy subject during stationary isometric contraction.* (*b*) *tremour e.m.g. of the extensor muscle group in the forearm of a patient with Parkinson's disease showing a resting tremour*

HOF and VAN DEN BERG (1977) and HOF (1980) show that the amplitude of the rectified and low-pass filtered e.m.g. is linearly proportional to the so-called 'active state' of a muscle. The active state is, in turn,

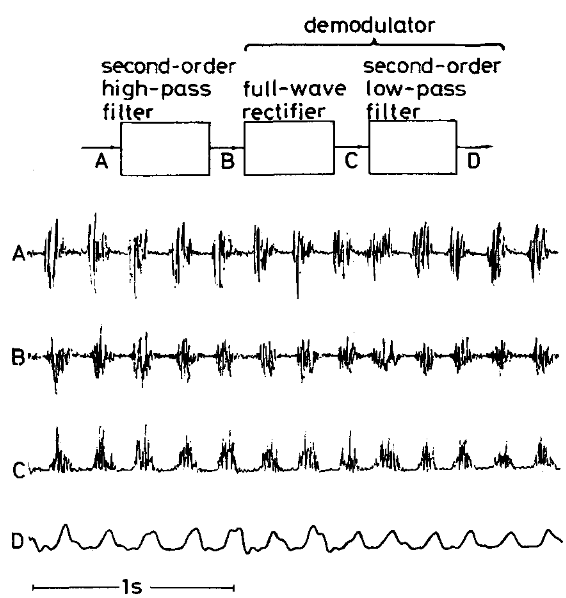

Fig. 2 *Block diagram of the demodulator, preceded by a high-pass filter for removing movement artefacts from the tremour e.m.g., together with the in- and output signals during a resting tremour.*

linearly related to the force developed by a muscle during slow, isoetric contraction. For fast contractions, such as occur in tremours, this relationship is very complex. However it can still be stated that, if the displacement of a muscle during a certain time interval $v(t)$ is constant and the s.r.e. (smoothed rectified e.m.g.) is magnified by a factor a, the force $F(t)$ is increased by the same factor a. In Shwedyk's model, which is based on alternating, isometric contractions of the biceps muscle, the e.m.g. of a tremour is considered as amplitude-modulated noise x_t. Thus the modulation signal itself is narrowband filtered white noise. This modulating signal is called the pure tremour signal m_t. The e.m.g. during a constant state of contraction, itself being broadband filtered noise, is the carrier n_t. This is expressed as

$$x_t = n_t(1 + Mm_t) \quad \ldots \ldots \ldots (1)$$

where M is a constant, being in practice commonly equal to one. In the test equipment of the demodulator M will be considered as the modulation depth. There is no physiological evidence for m_t and n_t having any statistical correlation.

3 Demodulation of a tremour e.m.g.

Fig. 2 shows a block diagram of the electronics of the demodulator as well as the input signal, the intermediate results and the output signal prior to full-wave rectification, which is the essential operation performed during the demodulation. The e.m.g. is filtered and low-frequency movement artefacts are removed. One can consider a movement artefact as an unwanted component of the e.m.g. signal resulting from movements of the electrodes relative to the skin and muscles. The filter used (block 1 in Fig. 2) is a second-order high-pass filter with a 3 dB cutoff frequency of 60 Hz. In an experimental check we confirmed that movement artefacts are at the most less than 1% of the power of the filtered e.m.g. One prerequisite is good electrical contact between the electrodes and the skin. Block 2 in Fig. 2 performs full-wave rectification which demodulates the amplitude-modulated e.m.g. into the tremour signal and broadband noise, being the detection noise. This noise is an essential consequence of the demodulation process. This has been theoretically verified by us. Block 3 is a second-order low-pass filter, primarily designed to eliminate the high-frequency components of the detection noise. The polygram recording shows that this results in considerably improved visibility of the tremour signal (signal D). The 3 dB cutoff of the filter is 15 Hz. A second reason for the filter is to avoid aliasing problems when digitising the signal for digital spectral analysis.

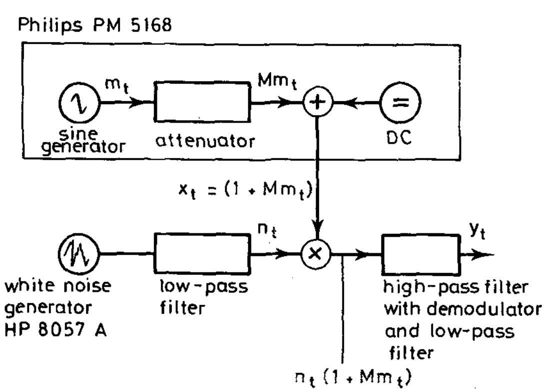

Fig. 3 *Block diagram of the test equipment for the demodulator. m_t is the modulating signal, n_t the broadband filtered noise as carrier, M the modulation depth, x_t the modulated and y_t the demodulated signal*

4 Characteristics of the demodulator

Fig. 3 shows in a block diagram the testing equipment of the demodulator. In this equipment a tremour e.m.g. is simulated by amplitude-modulated noise, according to eqn. 1. It is possible to change the modulating frequency f_m, the modulation depth M and the bandwidth B_n of the broadband noise. The 3 dB limitation of B_n, being equal to the 3 dB cutoff frequency of the first-order low-pass filter, is set at 60 Hz. Fig. 4 shows polygraphic recordings of the modulating signal m_t, the modulated signal m_t, the

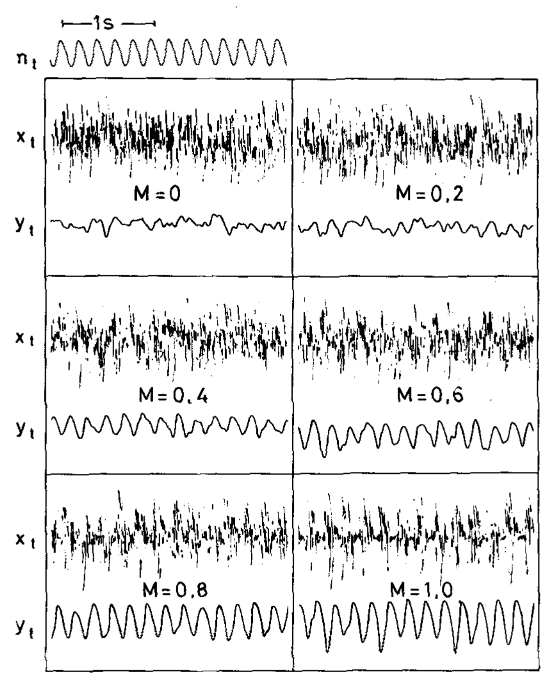

Fig. 4 *Some examples of results derived from the test equipment of Fig. 3. f_m = 5 Hz; B_n = 60 Hz. M is the modulation depth as a parameter*

modulated signal x_t and the results of the demodulation y_t at modulation depths of 0, 20, 40, 60, 80 and 100%. The detection level of the simulated tremour e.m.g. is about 60% by visual inspection, and of the demodulated signal about 20% modulation depth.

In other experiments the stationary e.m.g. of the flexor groups in the forearm of a healthy subject is used instead of artificially generated noise n_t. The hand was supine and carried a weight of about 400 g, and the elbow was supported. While keeping the rest of the test equipment unchanged, results similar to those in Fig. 4 and the detection levels already mentioned above were obtained.

5 Discussion

A tremour e.m.g. is in fact a form of tremour recording which is superior to mechanical registration, since it records directly at the origin of a muscular contraction whereas mechanical recordings are composed of weighted sums of contractions of muscle groups in various parts of the body. Mechanical recordings, for example, do not allow the distinction between contraction patterns of agonist and antagonist muscle groups in the forearm. E.m.g. recordings with surface electrodes, however, show a crosstalk between these muscle groups of at least 30 dB in the worst case. In this way it is possible to distinguish between alternating and 'in phase' tremours, which is of diagnostic value in recording pathological tremours.

Because of the nature of the tremour e.m.g., it is often difficult to recognise the tremour visually in a polygraphic recording. It is reasonable to consider the tremour e.m.g. as amplitude-modulated noise. Demodulation has been shown to improve the visibility of a tremour in the demodulated signal which is seen in a polygraphic recording. Expressed in modulation depth this improvement increases a detection level of 60% in the undemodulated e.m.g. to a level of 20% in the demodulated signal. The shape of the e.m.g. spectrum itself does not influence the performance of the demodulator. In as yet unpublished theoretical analysis of the demodulation of amplitude-modulated noise, it can be shown that the signal-to-noise ratio of the tremour signal in the demodulated e.m.g. depends only on the bandwidth of the modulated noise. Therefore the filtering characteristics of surface electrodes as calculated by LINDSTRÖM (1973) and electronic filters prior to full wave rectification are not critical for the results of demodulation. This makes a demodulator a useful tool in clinical tremour recording.

Despite the improvement of the detection level, the signal-to-noise ratio of the demodulated tremour e.m.g. is still poor. The noise in the demodulated tremour e.m.g. is spread out over a wide frequency range, whereas the tremour signal is a relatively narrowband noise. Spectral analysis is therefore recommended for a further improvement of the detection level.

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References

BRUMLIK, J. and YAP, C. B. (1969) *Normal tremor: a comparative study*. C. C. Thomas, Springfield, Illinois.

BRUMLIK, J. and MEANS, E. D. (1969) Tremorine-tremor, shivering and acute cerebellar ataxion in the adult and child. A comparative study. *Brain*, **92**, 157–190.

CALNE, D. B. and LADER, M. H. (1969) Electromyographic studies of tremor using an averaging computer. *Electroenc. Clin. Neurophysiol.*, **26**, 86–92.

HOF, A. L. and VAN DEN BERG, J. (1977) Linearity between the weighted sum of the human triceps surae and the total torque. *J. Biomechanics*, **10**, 529–539.

HOF, A. L. (1980) EMG to force processing. Thesis, Groningen Veenstra-Visser.

JUNG, R. (1941) Physiologische Untersuchungen über den Parkinsontremor und andere Zitterformen beim Menschen. *Z. Ges. Neurol. Psychiatr.*, **173**, 263–332.

KREIFELDT, J. G. (1969) An analysis of surface detected EMG as an amplitude modulated noise and its logarithmic detection. 8th ICMBE, Chicago.

KWATNY, E., THOMAS, D. H. and KWATNY, H. G. (1970) An application of signal processing techniques to study myoelectric signals. *IEEE Trans.*, **BME-17**, (4).

LINDSTRÖM, L. (1970) On the frequency spectrum of EMG signals. Report, Depts. Appl. Electr. and Clin. Neurophysiol., Chalmers University, Götenburg 7:70.

LINDSTRÖM, L. (1973) A model describing the power spectrum of myoelectric signals. Part 1. Single fibre signals. *ibid.*, 5:73.

MARSHALL, J. (1968) Tremor. In: *Handbook of neurology*, Vinken Bruin, North Holland, Amsterdam, Chap. 31.

MORGAN, M. H., HEWER, R. L. and COOPER, R. (1975) Intention-tremor: a method of measurement. *J. Neurol., Neurosurg. & Psychiatr.*, **38**, 353–358.

PELNÁR, J. (1913) *Das Zittern. Seine Erscheinungsformen, seine Pathogenese und Klinische Bedeutung*. J. Springer, Berlin.

SÄLTZER, M. (1975) Model zur beschreibung des Tremors. *Europ. J. Appl. Physiol.*, **34**, 19–31.

SATO, H. (1976*a*) Power spectral analysis of surface electromyograms during isometric contraction. *J. Anthrop. Soc. Nippon.*, **84**, 1–14.

SATO, H. (1976*b*) Some factors affecting the power spectra of surface electromyograms in isometric contractions. *ibid.*, **84**, 105–113.

SATO, H. (1977) Electromyographic study of muscular fatigue in sustained isometric contractions. *ibid.*, **85**, 83–94.

SCHWABB, R. S. and COBB, S. (1939) Simultaneous electromyograms and electroencephalograms in paralysis agitans. *J. Neurophysiol.*, **2**, 36–41.

SHWEDYK, E. R., BALASHUBRAMANIAN, R. and SCOTT, R. N. (1977) A non stationary model for the electromyogram. *IEEE Trans.*, **BME-24**, 417–424.