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BACKGROUND FOR REVISING EQUAL-LOUDNESS CONTOURS

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ABSTRACT
The international standard ISO 226 specifies thresholds of hearing and contours of equal loudness. The document was issued for the first time in 1961, and an editorial update was made in 1987. In connection with the update it was realized that results of new investigations did not agree with data of the document. ISO Technical Committee 43, "Acoustics", therefore decided to start a full-scale revision. Until now, the work has resulted in a separate standard with data for the hearing threshold, while a proposal for a completely revised ISO 226 is awaited in the near future. The paper presents the history of ISO 226, including the arguments for its revision, and it summarizes the present state as an introduction to the following papers of the session.

1 - ISO R226:1961

Work on standardization of equal loudness contours and the hearing threshold began in 1957 under ISO Technical Committee 43, "Acoustics". This work led in 1959 to the adoption of a Draft ISO Recommendation (No. 352), which was circulated to the ISO Member Bodies. Subject to a few modifications of an editorial nature, it was approved by 26 member bodies as an ISO Recommendation, ISO R226:1961 [1]. Only Germany opposed to the approval.

ISO R226:1961 specified curves of equal loudness in a graphical form, showing curves from 6 phon to 140 phon (in intervals of 2 phon). The hearing threshold was also given, denoted minimum audible field (MAF). The data were given for otologically normal persons listening binaurally to pure tones in a free sound field with a frontal sound incidence. The frequency range was 20 Hz to 15 kHz, and the dynamic range was limited to 140 dB sound pressure level at low frequencies and 130 dB at high frequencies. An annex ("for information only") expressed, for a given frequency, the loudness level in terms of a loudness growth function as a second order polynomial of sound pressure level. The three coefficients of the polynomial as well as the threshold of hearing (which could also be denoted and calculated as the 4.2 phon curve, since the hearing threshold was 4.2 dB at 1 kHz) were given for 49 frequencies between 20 Hz and 15 kHz, spaced between 5 Hz (at the lowest frequencies) and 1 kHz (at highest frequencies). The age range for the main data of ISO R226:1961 is stated as 18-25 years, but the document has an appendix ("for information only") with correction formulae for the age of listeners. Data of ISO R226:1961 are given with broken lines in Figure 1.

The data of ISO R226:1961 were based on a comprehensive investigation made by Robinson and Dadson [2]. Their experiments included up to 120 test subjects and covered the frequency range 25 Hz-15 kHz and levels up to 129 dB. The main part of the experiment was made in a free-field environment, but at low frequencies the listeners were placed with head and shoulders inside a duct, which established a free progressive wave. As seen from the frequencies and levels covered by the investigation, the data of ISO R226:1961 at the lowest frequencies and at the highest levels must have been extrapolated.

At the time ISO 226:1961 was made, other researchers had also published data on the hearing threshold and equal-loudness contours. Sivian and White [3], Fletcher and Munson [4], Churcher et al. [5], and Churcher and King [6] had determined thresholds of hearing in free field. Kingsbury [7], Fletcher and Munson [4], Churcher and King [6], and Zwicker and Feldtkeller [8] had made studies of equal loudness contours. All these studies of equal loudness had been made with headphones, either binaurally or

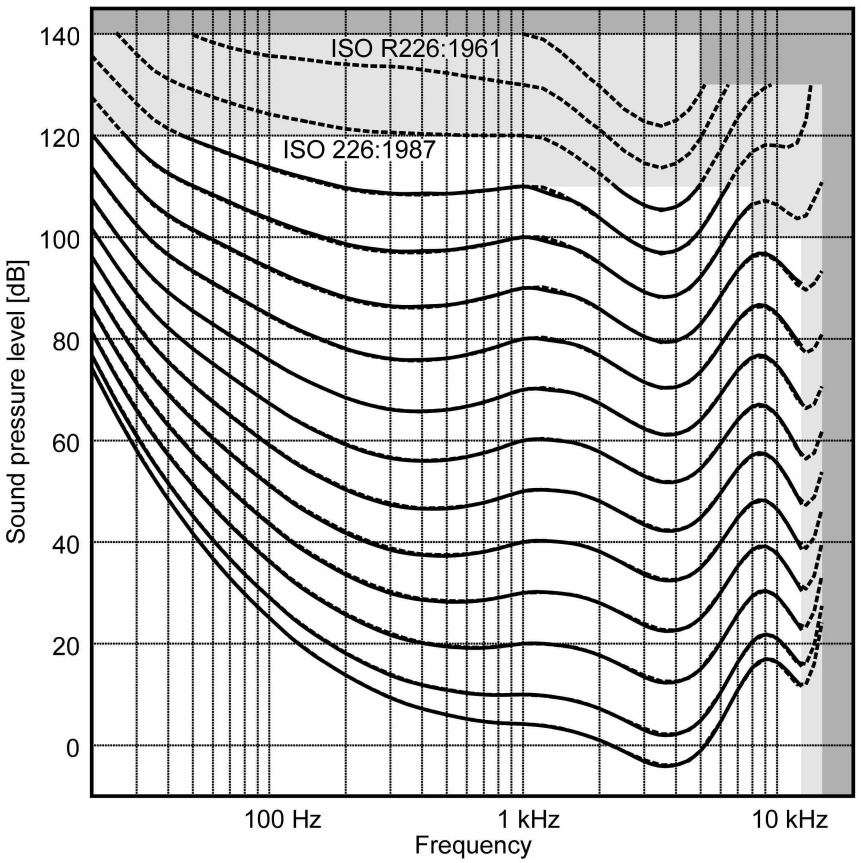

Figure 1: Free-field hearing thresholds and equal loudness contours from ISO R226:1961 (broken lines, partly behind continuous lines) and from ISO 226:1987 (continuous lines); limits at high levels and at high frequencies indicated by shaded areas.

monaurally. However, the latter three had made an attempt to refer to corresponding sound pressure levels of a free field. Although the bibliography of ISO R226:1961 referred to four studies ([3], [4], [6], [2]), a look at the data reveals that only data of Robinson and Dadson [2] had been used. Ironically, equal loudness contours are often denoted Fletcher-Munson curves.

2 - ISO 226:1987

As a result of a mandatory renewal procedure it was decided to give ISO R226:1961 an editorial update and at the same time change it from a Recommendation to a Standard. In connection with the updating process the responsible working group became aware that new data had been published which did not agree with the data of ISO R226:1961. The new data could not immediately be taken into account without changing the complete technical basis of the document and it was decided to continue the editorial updating, while starting in parallel the process of a full-scale revision.

As a result of the editorial update, a Draft International Standard ISO/DIS 226 was circulated and approved in 1985 (all 26 member bodies in favor), and it was issued in 1987 as ISO 226:1987 [9]. Although it was claimed to be updated only editorially, some changes had been employed. The main specifications were now given in mathematical and tabular form, while the graphic presentation (now with 10 phon intervals between curves) had been moved to an annex. The mathematical specification had been changed to a bilinear form, still giving, for a certain frequency, the loudness level as a function of sound pressure level. The three (new) constants of the formula (of which the hearing threshold was now one) were given at the 29 third-octave frequencies from 20 Hz to 12.5 kHz (third-octave frequencies had in the meantime been standardized as "preferred frequencies" in ISO 266:1975 [10]).

Despite of the changes, the data material was virtually unchanged but the upper frequency limit had been lowered from 15 kHz to 12.5 kHz, and the dynamic range had been restricted to 120 dB at low frequencies, 110 dB at middle frequencies and 100 dB at the highest frequencies. Evidently, doubt must have been raised about the data at the highest frequencies and at the highest levels of the former version. In the bibliography, references to the publications, which had not been used, were deleted ([3], [4], [6]).

Values of ISO 226:1987 are given with continuous lines in Figure 1.
The age range was now stated as 18−30 years. The appendix about effect of age had been removed, since this information had been separately standardized in much more detail in ISO 7029:1984 [11]. Finally, the relation between listening in free field with frontal sound incidence and diffuse-field listening was included in the standard. This information had previously been covered by ISO 454:1975 [12], and the data had been taken directly from this. ISO 454:1975 was withdrawn as a result of the approval of ISO 226:1987.

3 - PROPOSAL FOR REVISION

The proposal for a full-scale revision was officially put forward by the German member body at the TC 43 Plenary Meeting in Budapest, Hungary [13]. For the hearing threshold the proposal referred to new data published by Berger [14]. At that time hearing thresholds were also available from Brinkmann [15] (but not used in the argumentation). Figure 2 compares these data with those of ISO R226:1961.

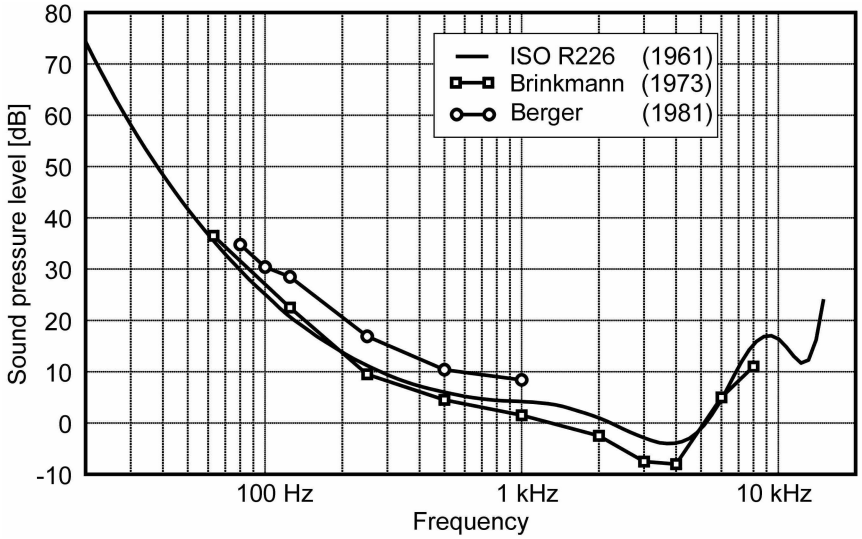

Figure 2: Free-field hearing threshold from ISO R226:1961 and thresholds measured in two studies, which were available when the revision was proposed.

For the equal loudness curves the German proposal referred to recent work by Zwicker and coworkers at the Technical University of Munich, which allegedly had reconfirmed earlier studies ([4], [6], [8] and Zwicker [16]). As mentioned above (except for [16]) data from these studies had not been used in ISO R226:1961, and it was argued that the document's data in the frequency range from 200 Hz to 1 kHz were incorrect, at least for sound pressure levels around 70 dB. The recent work by "Zwicker and coworkers" is most probably the study published later by Fastl and Zwicker [17]. At the time when the revision was proposed, data at low frequencies were also available from Kirk [18] and from Møller and Andresen [19] (although not used in the argumentation). Figure 3 shows data of ISO R226:1961 and measured data at two selected loudness levels. The most severe deviations are seen in the frequency range below 1 kHz and at low level.

4 - WORKING GROUP CONSIDERATIONS

In the following years a number of different investigations were made on thresholds (Kumagai et al. [20], Betke and Mellert [21] (later reported in more detail by Betke [22]), Fastl et al. [23], Watanabe and Møller [24], Watanabe and Møller [25],Vorländer [26]), and equal loudness contours ([20], Betke et al. [27], Suzuki et al. [28], [23] ([24])). The threshold data seemed fairly consistent between laboratories, but significant differences were still observed between equal loudness data. As an instrument in improving the consistency of data, the responsible working group agreed on a set of test conditions, which should preferably be fulfilled in experiments producing data for standardization, not only for ISO 226, but for audiometric standards in general [29] (later made available in [30]).
Since new data on the hearing threshold were highly demanded for calibration of free-field audiometers and since these data could be standardized nearly right away, it was decided to split the revision of ISO 226 into two steps. Hearing thresholds were published in ISO 389-7:1996 [31] (part of a series of standards for calibration of audiometric equipment), while the revision of equal loudness contours had

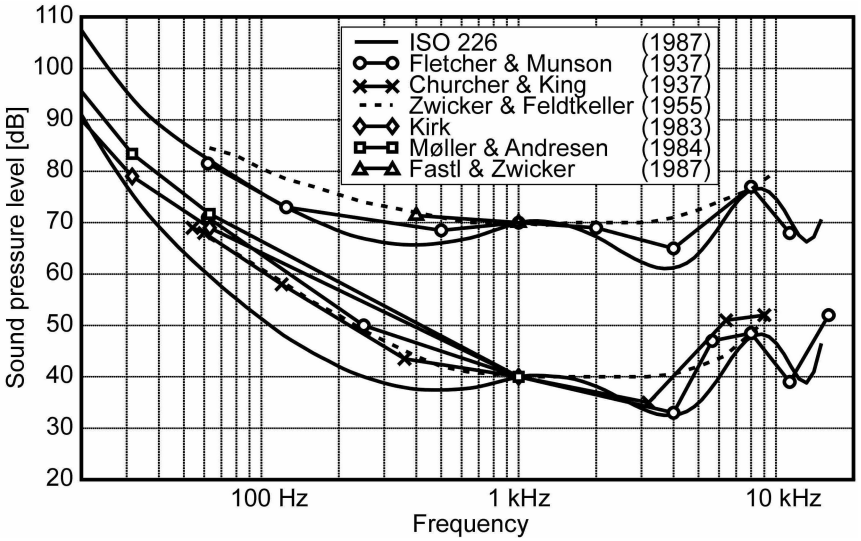

Figure 3: Examples of free-field equal loudness contours (40 phon and 70 phon) from ISO R226:1961 and points of the same contours as measured in various studies, which were available at the time when the revision was proposed.

to await data from more laboratories and hopefully a clarification of the discrepancies. The continued work on this matter has led to the present state where the disagreements have mostly been explained, in particular with bias from the psychophysical methods and other experimental differences. A proposal for a completely revised ISO 226 is awaited from the working group in the near future.

5 - THRESHOLDS IN ISO 389-7:1996

ISO 389-7:1996 is based on the original data by Robinson and Dadson [2] and 7 more recent investigations: Brinkmann [15], Betke and Mellert [21] (Betke [22]), Suzuki et al. [28], Fastl et al. [23], Vorländer [26], Watanabe and Møller [24], [25]. Brinkmann [32] has described the compilation of data in detail. Threshold data from ISO 226:1987 and ISO 389-7 are shown in Figure 4. It is seen that the difference between the two threshold curves is small ($\leq$ 3.8 dB).

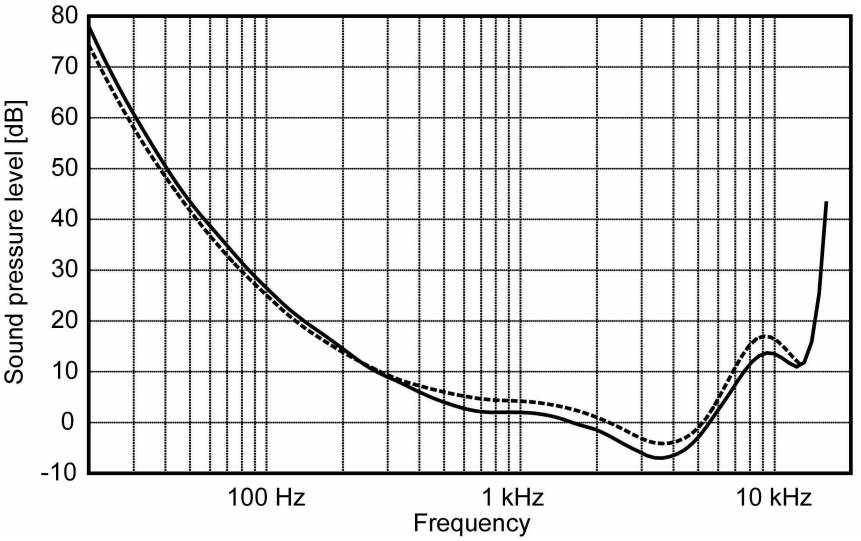

Figure 4: Free-field hearing thresholds from ISO 226:1987 (broken line) and ISO 389−7:1996 (continuous line).

ACKNOWLEDGEMENTS

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REFERENCES

1. **ISO R226:1961**, *Normal equal-loudness contours for pure tones and normal threshold of hearing under free field listening conditions*, 1961

2. **Robinson, D.W. and Dadson, R.S.**, A re-determination of the equal-loudness relations for pure tones, *Br. J. Appl. Phys.*, Vol. 7, pp. 166-181, 1956

3. **Sivian, L.J. and White, S.D.**, On minimum audible sound fields, *J. Acoust. Soc. Am.*, pp. 288-321, 1933

4. **Fletcher, H. and Munson, W.A.**, Loudness, its definition, measurement and calculation, *J. Acoust. Soc. Am.*, Vol. 5, pp. 82-108, 1933

5. **Churcher B.G., King, A.J. and Davies, H.**, The measurement of noise with special reference to engineering noise problems, *J. Inst. Electr. Eng.*, Vol. 75 (454), pp. 401-446, 1934

6. **Churcher, B.G. and King, A.J.**, The performance of noise meters in terms of the primary standard, *J. Inst. Electr. Eng.*, Vol. 81, pp. 57-90, 1937

7. **Kingsbury, B.A.C.**, A direct comparison of the loudness of pure tones, *Phys. Rev.*, Vol. 29, pp. 588-600, 1937

8. **Zwicker, E. and Feldtkeller, R.**, Über die Lautstärke von Gleichförmigen Geräuschen, *Acoustica* , Vol. 5, pp. 303-316, 1955

9. **ISO 226:1987**, *Acoustics - Normal equal-loudness level contours*, 1987

10. **ISO 266:1975**, *Acoustics - Preferred frequencies for measurements. (Now replaced by ISO 266:1997, Acoustics - preferred frequencies)*, 1975

11. **ISO 7029:1984**, *Acoustics - Threshold of hearing by air conduction as a function of age and sex for otologically normal persons, (Now replaced by ISO 7029:2000, Acoustics - Statistical distribution of hearing thresholds as a function of age.)*, 1984

12. **ISO 454:1975**, *Relation between sound pressure levels of narrow bands of noise in a diffuse field and in a frontally-incident free field for equal loudness*, 1975

13. **ISO/TC 43 N274**, *Proposal from the German member body for a new work item proposal: Revision of ISO 226, February 1985*, 1985

14. **Berger, E.H.**, Re-examination of the low-frequency (50-1000 Hz) normal threshold of hearing in free and diffuse sound fields, *J. Acoust. Soc. Am.*, Vol. 70 (6), pp. 1635-1645, 1981

15. **Brinkmann, K.**, Audiometer-Bezugsschwelle und Freifeld-Hörschwelle, *Acustica*, Vol. 28, pp. 147-154, 1973

16. **Zwicker, E.**, Lautstärkeberechnung im Vergleich, *Acustica*, Vol. 17, pp. 278-284, 1966

17. **Fastl, H. and Zwicker, E.**, Lautstärkespegel bei 400 Hz. Psychoakustische Messung und Berechnung nach ISO 532 B, In *DAGA 1987*, pp. 189-192, 1987

18. **Kirk, B.**, *Hørestyrke og genevirkning af infralyd (in Danish)*, Institute of Electronic Systems, Aalborg University, Denmark, pp. 1-111, 1983

19. **Møller, H. and Andresen, J.**, Loudness of pure tones at low and infrasonic frequencies, *J. Low Freq. Noise Vib.*, Vol. 3 (2), pp. 78-87, 1984

20. **Kumagai, M., Suzuki, Y., Sawai, S., Kono, S., Sone, T., Miura, H. and Kado, H.**, Reexamination of equal-loudness contours for pure tones and threshold of hearing, In *Inter-Noise 1987, Beijing, China*, pp. 1001-1004, 1987

21. **Betke, K. and Mellert, V.**, New measurements of equal-loudness level contours, In *Internoise 1989 Newport Beach, Ca, USA*, pp. 793-796, 1989

22. **Betke, K.**, New hearing threshold measurements for pure tones under free-field listening conditions, *J. Acoust. Soc. Am.*, Vol. 89 (5), pp. 2400-2403, 1991

23. **Fastl, H., Jaroszewski, A., Schorer, E. and Zwicker, E.**, Equal loudness contours between 100 and 1000 Hz for 30, 50 and 70 phon, *Acoustica*, Vol. 70, pp. 197-201, 1990

24. **Watanabe, T. and Møller, H.**, Hearing thresholds and equal loudness contours in free field at frequencies below 1 kHz, *J. Low Freq. Noise Vib.*, Vol. 9 (4), pp. 135-148, 1990

25. **Watanabe, T. and Møller, H.**, Low frequency hearing thresholds in pressure field and in free field, *J. Low freq. Noise Vib.*, Vol. 9 (3), pp. 106-115, 1990

26. **Vorländer, M.**, Freifeld-Hörschwellen von 8 kHz - 16 kHz, In *DAGA 1991*, pp. 533-536, 1991

27. **Betke, K. Schulte-Fortkamp, B., Weber, R. and Remmers, H.**, Kurven gleicher Lautheit im Frequenzbereich 50 Hz bis 1 kHz, In *DAGA 1987, Aachen, Germany*, pp. 193-196, 1987

28. **Suzuki, S., Suzuki, Y., Kono, S., Sone, T., Kumagai, M., Miura, H. and Kado, H.**, Equal loudness level contours for pure tones under free field listening conditions (I) - Some data and considerations on experimental conditions, *J. Acoust. Soc. Jpn., (E)*, Vol. 10 (6), pp. 229-338, 1989

29. **ISO/TC 43/WG 1 N 122**, *Preferred test conditions for the determination of the minimum audible field and the normal equal-loudness level contours (revision of ISO 226)*, 1988

30. **ISO/TC 43/WG 1**, Preferred test conditions for determining hearing thresholds for standardization, *Scand. Audiol.* , Vol. 25, pp. 46-52, 1996

31. **ISO 389-7:1996**, *Reference zero for the calibration of audiometric equipment - part 7: Reference threshold of hearing under free-field and diffuse-field listening conditions* , 1996

32. **Brinkmann, K.**, Audiometer-Bezugsschwelle und Freifeld-Hörschwelle, *Acoustica*, Vol. 28, pp. 147-154, 1973