1972

Requirements for a Good Acoustic Laboratory

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Kjeldsen, K., "Requirements for a Good Acoustic Laboratory" (1972). *International Compressor Engineering Conference.* Paper 51.
https://docs.lib.purdue.edu/icec/51

REQUIREMENTS FOR A GOOD ACOUSTIC LABORATORY

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INTRODUCTION

It is a well-known fact that the compressor manufacturer in the course of time has been obliged to show some interest in the noise caused by his products.

The necessity becomes greater as the competition increases. It is becoming clear to the customer that noise is not absolutely necessary to achieve the primary object, namely refrigeration.

At the same the authorities are setting up rules stating how much noise we may produce in and outside our houses. For refrigeration compressors it is fortunately a question of annoyance, rather than a question of high noise levels.

In the past a lot has been written about noise testing and noise evalution methods, some usable, but also some so sophisticated that they were impossible to use in practise. In the last ten years a crystallization of the best of the methods has taken place, and within ISO usable standards and drafts are on their way (1), which is of great satisfaction. It would be gratifying if all those national standards could be replaced by international standards, thereby making it possible to speak the same language.

REQUIREMENTS

What is the requirements to a good acoustic laboraty from the point of view of a compressor manufacturer and his customer?

The primary object must be to own "a tool" which facilitates the manufacturing of a silent compressor.

1. For that purpose we shall of course need people with sufficient education and imagination to handle the problémes in the correct manner.
2. Furthermore we shall have to purchase special measuring equipment in order to carry out the necessary detail analysis of the various components and parametres influencing the noise level. Things like valve examination, muffler calculation and investigation, spring and discharge tube analysis, and compressor shell investigation can be mentioned.
3. We need measuring surroundings (test rooms) enabling us to carry out objective measuring with possibilities for sound power determination, with an accuracy as stated in international standards.
   The measuring room should also be acoustical adjusted (frequency independent reverberation time) so that it enables us to carry out a subjective evaluation of the noise character (pendling, discrete frequencies, time variation, etc). Such an "adjustment" will also facilitate tape recordings of diverse equipment during testing and replay in front of an audience for pronouncement.
4. The measuring procedure must be practicable in time as it is normally necessary to carry out measurements on several samples, and at more than one running condition.
   This is tantamount to measuring equipment with automatic data acquisition, which together with a digital computer admits an easy access for all desired calculating such as sound power level, noise evaluation, statistical tests, etc.

The following contains a review of the procedure with which we attempted to meet the requirements under points 3 and 4.

TYPES OF TEST ROOMS

It is commonly known that a reverberant room offers great advantages in regard to cost and test effort, compared with an anechoic room (2,3). The disadvantage is by and large limited to the problem of obtaining sufficient space averaging of the sound pressure when testing equipment whose spectra contains narrow bands of noise(4.5)

Our reverberant test rooms (two identical rooms, constructed in 1968) are of the conventional rectangular type with data in accordance with several standards and draft proposals (6.7). The room volume is 200m^3. Further data for the rooms are stated at the top right corner of figure 5.

In order to be able to measure equipment with extremely low noise levels the rooms are built with double walls. The inside room is vibration insulated by means of rubber springs. Background noise levels (room + measuring instruments) are stated as function of frequency in figure 5 (in table).

Reverberation time adjustment and diffusing elements.

The room were constructed with inside surfaces as hard as possible to create a high reverberation time at the high frequencies. After the finishing of the building, regulation of the room absorption was made for two reasons:

1. To increase the bandwidth of the resonance curves of the normal modes of the room, particularly at the low frequencies.
2. By and large to obtain a frequency-independent reverberation time for the possibility of making an auditive evaluation of noise from the test object as mentioned (see figure 1).

Most of the absorbing elements are made of perforated and unperforated aluminium panels. The elements were placed at random and at various angels to the room surface to work as diffusors, also. A final regulation was carried out by means of "tuned membrane absorbers" suspended in the room. Further diffusion was made in the ceiling construction (see figure 2).
There are now revolvable or oscillating diffusors in the room. Space averaging is made by a traversing microphone which moves with a constant velocity (0.4m/sec) over a path of two metres.

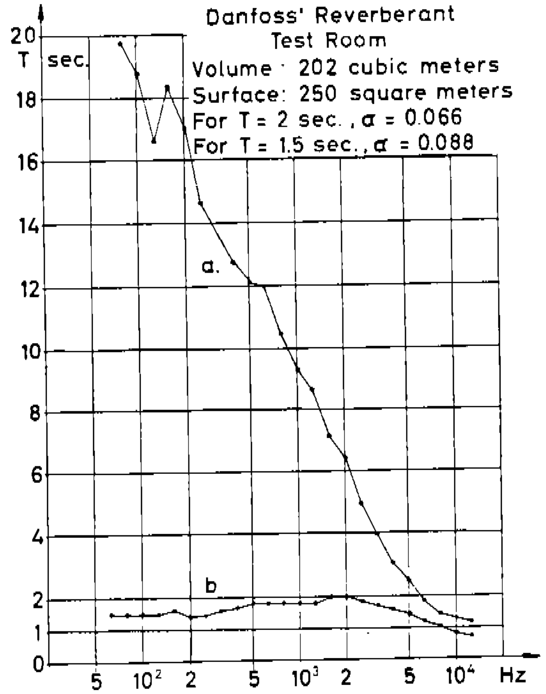

Fig.1 Reverberation Time versus Frequency
a. Before regulation.
b. After regulation.

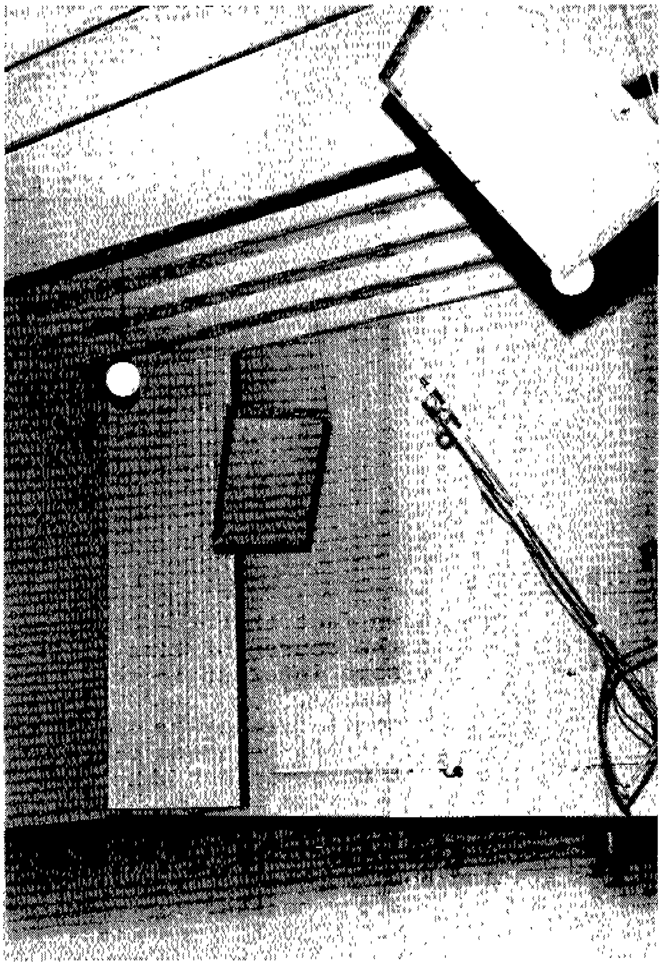

Fig. 2. Interior of test room.

INSTRUMENTATION

As measuring equipment are used a 1/3 octave band Real Time Analyser (B & K, type 3347) with continuous time averaging (RC-smoothing) with time constant equal to 20 seconds. The analyser is connected to a tape punch B&K type 5582). A Manual Data Extension Unit (B & K, type 5599) gives the possibility for information on sample type and number, running conditions, etc, (see figure 3).
The data measured can then be calculated in a digital computer.

QUALIFICATION OF THE TEST FACILITIES

To examine the quality of the room, various measurings have been carried out on two different types of noise sources.

1. The conventionally used ILG-Reference Sound Source (broad band noise)
2. Selected compressor with narrow bands of noise and discrete frequencies.

Re.1. Figure 4 shows the sound pressure levels for the sound source (RSS) versus distance to microphone. From 125 Hz and up to 8 kHz we have very smooth sound pressure levels over a long distance except at 250 Hz. Qualification test for broad band noise

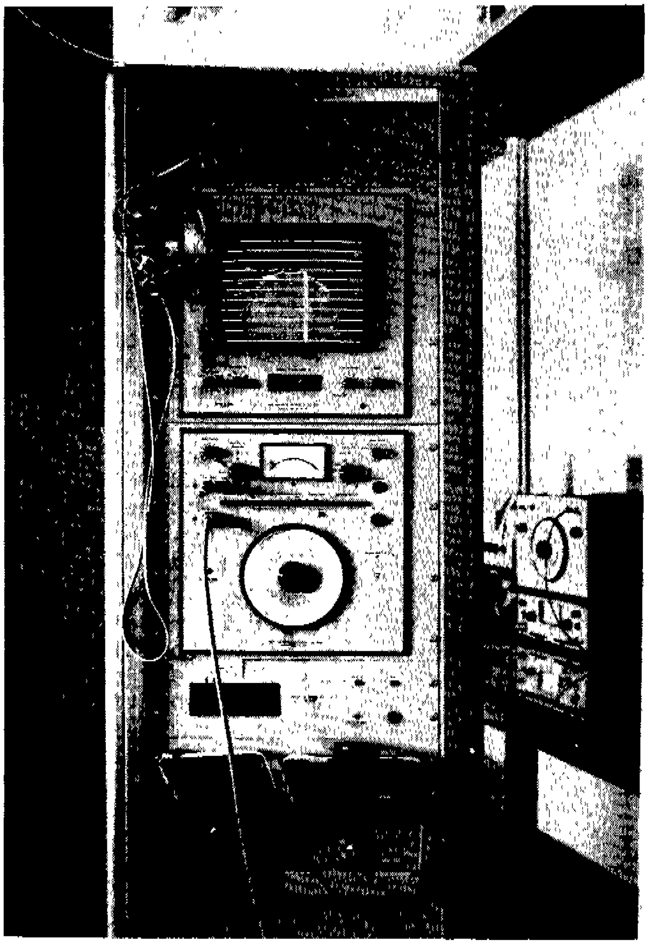

Fig.3 Real-Time Analyser with Paper Tape Punch Unit.

measurements in accordance with the new ISO draft (7) are shown in figure 5a and 5b. The requirements are more than satisfied except the 100 Hz 1/3 octave band.

Other measurements (not shown here) show that one source location and the microphone traversed with constant velocity over a path of two metres, gives measuring uncertainty which is less than that mentioned in the new ISO-draft (7).
With a carefully selected fixed microphone location, the uncertainty will only be slightly increased, which is important when recording on tape recorders.
Re 2. When measuring sources with narrow bands of noise and discrete frequency, one must be more careful. Figure 6 shows measurings on a compressor, which, after the definitions in the ISO (7) part II, have narrow bands of noise with 315, 400, 800, 1600 and 2000 Hz and discrete frequencies with 500 and 1000 Hz.
Figure 7 shows measurings and statistical test with the compressor location moved 0.7 metres from the above mentioned. There were only significant deviations in a very few 1/3 octave bands.
Finally, figure 8 shows a statistical test between the measurings from figure 6 and ten measurings taken at intervals of one minute on the same compressor, but with fixed microphone located in the centre of the microphone path.
As expected there are significant differences between several frequency bands, but the deviations are modest.

PRESENTATION OF MEASURED AND CALCULATED DATA

Figure 5 to 8 also shows clear examples of how to present the measured sound pressure levels, calculated sound power levels and statistical test.
The applied equation for sound power level calculation

$$Lw = Lp + \left[10 \log_{10} V - 10 \log_{10} T - 14\right] \text{dB}$$

has to be changed to

$$Lw = Lp + \left[10 \log_{10} V - 10 \log_{10} T + 10 \log_{10}\left(1 + \frac{S\cdot\lambda}{8\cdot V}\right) - 14\right] \text{dB}$$

to account for the effect of the interference pattern formed near the room surfaces, ISO part II (7).

FINALLY COMMENTS

Mentioned here are some of the most important requirements for a good acoustic laboratory, withhout, however, all the details.

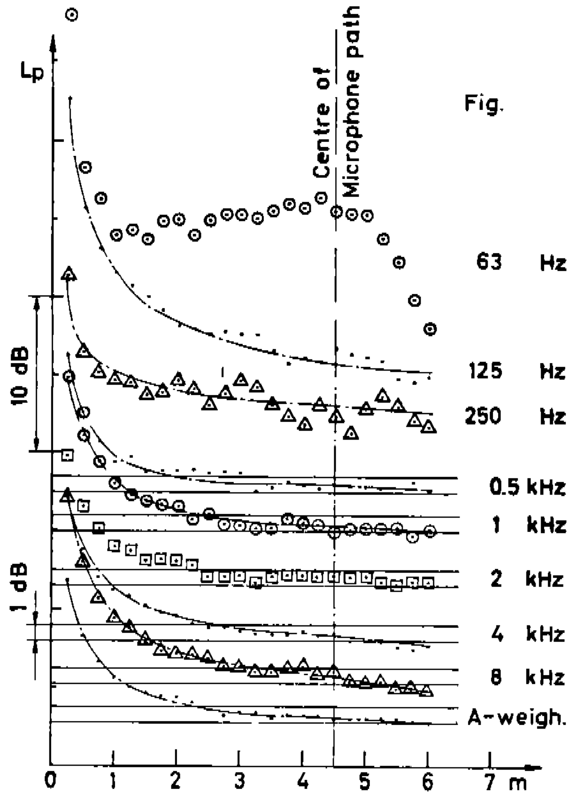

Fig. 4.
Sound Pressure Levels for Reference Sound Source versus Distance to Microphone.

Of the factors which are significant for the sound power calculations are things like accuracy when adjusting the measuring equipment and the determination of reverberation time.

Oscillating or rotating diffusors are often used in reverberant test rooms, but one of the factors connected with this must be made clear. Such diffusors cannot operate during tape recordings, since space variations of the sound pressure level in the test room will be conceived as time variation of the test object.

The length of the microphone path we use is much less than demanded by ISO for measuring at discrete frequencies, but it is a question of whether this point is still too sophisticated?

It must be better having the other facilities in order, with the possibility to make compressors witout pure tones than being able to measure with the utmost precision on a bad product!

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7. ISO Draft Proposal for Determination of Sound Pover Emitted by small Noise Sources in Reverberation Rooms.

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***    TEKNISK EDB, DANFOSS, NORDBORG.    PROGRAM M3054    ***

*******************************************************************************************************
* NOISE MEASUREMENTS ON  REFERENCE SOUND SOURCE                * THE MEASUREMENTS ARE TAKEN IN A REVERBERANT TEST ROOM *
* WITH CALCULATION OF                                          * WITH THE FOLLOWING DATA                               *
* LP = MEAN SOUND PRESSURE LEVEL IN 1/3 OCTAVE BANDS           * LENGTH X WIDTH X HEIGHT = 8.7M X 6.0M X 4.1M          *
* S  = STANDARD DEVIATION                                      * VOLUME V = 212 -(VOL. OF ABSORBERS ETC.) = 202 M**3   *
* LW = MEAN SOUND POWER LEVEL IN 1/3- AND 1/1 OCTAVE BANDS     * REVERBERATION TIME = T SEC (SEE TABLE)                *
* CAL. AS  LW = LP +(10LOGV -10LOGT -14) = LP +K (K SEE TABLE) * BACKGROUND SOUND PRESSURE LEVEL = LPBAC (SEE TABLE)   *
* LW(A)= THE WEIGHTED SOUND POWER LEVEL IN DB(A)               *                                                       *
*******************************************************************************************************

     TEST OBJECT      ILG. RSS *  220 VOLT *      ROOM      TEMP.  20 C *   MF. DATE          * CODE  1
    11 MIK.POS. 1RSS.POS.      *   50 HZ   *  60% REL. HUM.             *  MES.  -*- 03.06.72 *

T SEC 1.5 1.5 1.5 1.5 1.5 1.6 1.4 1.4 1.6 1.7 1.8 1.8 1.8 1.8 1.8 2.0 2.0 1.8 1.7 1.6 1.4 1.2 1.0 0.8 0.7
LPBAC  19  15  12  10  12  10   8   8   7   6   6   5   5   5   5   5   5   5   6   6   6   6   6   6   6

BAND   17  18  19  20  21  22  23  24  25  26  27  28  29  30  31  32  33  34  35  36  37  38  39  40  41  47
     HZ50  63  80 100 125 160 200 250 315 400 500 630 800  1K 1.2 1.6  2K 2.5 3.2  4K  5K 6.3  8K 10K 12K DBA
NUMBER
1100  620 684 584 606 598 616 614 618 646 636 634 634 640 644 648 652 646 624 612 588 576 566 534 482 420 746
1000  620 690 568 594 590 614 612 618 640 634 634 636 642 644 650 658 646 622 612 586 576 562 532 480 414 746
 900  602 666 562 594 586 618 606 620 640 642 642 640 642 646 646 660 644 624 610 586 572 562 534 484 414 746
 800  610 682 552 582 588 618 604 612 640 630 648 632 642 642 644 646 642 620 610 588 574 566 536 484 416 742
 700  606 668 550 580 582 612 616 616 644 630 648 642 644 646 644 650 648 622 610 590 576 558 534 482 412 746
 600  600 664 544 570 584 608 620 612 628 632 640 642 640 636 644 652 646 622 610 586 572 560 532 478 404 744
 500  592 660 544 560 582 612 624 624 632 636 638 638 642 638 642 652 644 624 608 584 572 556 530 476 402 742
 400  586 652 538 556 576 606 606 620 628 636 634 634 646 638 646 648 642 618 604 582 568 550 528 472 400 740
 300  582 638 534 548 576 618 614 636 634 646 644 634 640 638 644 644 644 620 608 586 570 550 530 472 400 742
 200  580 632 532 540 570 612 606 632 626 634 640 636 642 640 642 640 640 618 606 582 570 554 526 470 396 740
 100  580 616 526 540 570 618 616 632 626 634 630 642 646 638 644 644 642 618 608 584 570 556 528 470 396 742

LP*10 598 659 549 570 582 614 613 622 635 635 639 637 642 641 645 650 644 621 609 586 572 558 531 477 407 74.3
S     1.5 2.3 1.7 2.3 0.9 0.4 0.6 0.8 0.7 0.5 0.6 0.4 0.2 0.4 0.2 0.6 0.2 0.2 0.2 0.3 0.3 0.6 0.3 0.6 0.9 0.2

K     7.2 7.2 7.2 7.2 7.1 7.0 7.4 7.4 7.0 6.7 6.5 6.2 6.2 6.2 6.2 6.0 5.9 6.2 6.6 7.0 7.6 8.2 9.0 9.7 10.6
LW1/3 670 731 621 642 653 684 687 696 705 702 704 699 704 703 707 710 703 683 675 656 648 640 621 574 513

LW1/1     74.3        71.1        74.4        74.9        75.2        74.7        70.8        66.7

THE WEIGHTED SOUND POWER LEVEL LW(A)= 80.5 DB(A)
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Fig.5 a.

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***   TEKNISK EDB, DANFOSS, NORDBORG.   PROGRAM M3054   ***

MEAN SOUND PRESSURE LEVEL, STANDARD DEVIATION AND SPECTROGRAM FOR
      TEST OBJECT:   ILG. RSS *  220 VOLT *       ROOM     TEMP.  20 C *   MF. DATE            * CODE  1
    11 MIK.POS. 1RSS.POS       *    50 HZ   *     60% REL. HUM.          *  MES.  -*- 03.06.72 *

     HZ50  63  80 100 125 160 200 250 315 400 500 630 800  1K 1.2 1.6  2K 2.5 3.2  4K  5K 6.3  8K 10K 12K DBA

LP*10 598 659 549 570 582 614 613 622 635 635 639 637 642 641 645 650 644 621 609 586 572 558 531 477 407 74.3
S     1.5 2.3 1.7 2.2 0.8 0.4 0.6 0.8 0.7 0.4 0.5 0.3 0.2 0.3 0.2 0.6 0.2 0.2 0.2 0.2 0.2 0.5 0.3 0.5 0.8 0.2


    SPECTROGRAM FOR CALCULATED MEAN SOUND PRESSURE LEVEL AND + 2 TIMES THE STD DEVIATION

       0        10        20        30        40        50        60        70        80        90 DB
       I    .    I    .    I    .    I    .    I    .    I    .    I    .    I    .    I    .    I
HZ50   ************************************************************0---
  63   ******************************************************************6----
  80   *******************************************************5---
 100   *********************************************************7----
 125   **********************************************************8--
 160   *************************************************************1
 200   *************************************************************1-
 250   **************************************************************2--
 315   ****************************************************************4-
 400   ****************************************************************4
 500   ****************************************************************4-
 630   ****************************************************************4
 800   ****************************************************************4
  1K   ****************************************************************4
 1.2   *****************************************************************5
 1.6   *****************************************************************5-
  2K   ****************************************************************4
 2.5   **************************************************************2
 3.2   *************************************************************1
  4K   ***********************************************************9
  5K   *********************************************************7
 6.3   ********************************************************6-
  8K   *****************************************************3
 10K   ************************************************8-
 12K   *****************************************1--
 DBA   **************************************************************************4
       I    .    I    .    I    .    I    .    I    .    I    .    I    .    I    .    I    .    I
       0        10        20        30        40        50        60        70        80        90 DB
```

Fig. 5 b.

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***   TEKNISK EDB, DANFOSS, NORDBORG.   PROGRAM M3054   ***

MEAN SOUND PRESSURE LEVEL, STANDARD DEVIATION AND SPECTROGRAM FOR
  1 COMPRESSOR  TYPE PW4.5K9  *  220 VOLT *  EVAPORATING TEMP. -25 C *   MF. DATE          * CODE  6
    1 SC.POS. 11 MIK.POS        *   50 HZ   *   CONDENSING  -*-   55 C *  MES.  -*- 03.06.72 *

     HZ50  63  80 100 125 160 200 250 315 400 500 630 800  1K 1.2 1.6  2K 2.5 3.2  4K  5K 6.3  8K 10K 12K DBA

LP*10 193 145 133 121 120 130 125 137 148 157 251 122 121 158 113 178 273 204 169 137 120 106 110  98 111 31.6
S     1.0 0.2 0.2 0.3 0.7 0.4 1.2 0.7 1.8 2.3 3.7 1.1 1.7 3.2 0.5 1.7 1.8 0.7 1.2 0.5 0.2 0.2 0.0 0.1 0.2 1.3


    SPECTROGRAM FOR CALCULATED MEAN SOUND PRESSURE LEVEL AND + 2 TIMES THE STD DEVIATION

       0        10        20        30        40        50        60        70        80        90 DB
       I    .    I    .    I    .    I    .    I    .    I    .    I    .    I    .    I    .    I
HZ50   *******************9--
  63   ***************5
  80   *************3
 100   ************2
 125   ************2-
 160   *************3
 200   *************3--
 250   **************4-
 315   ***************5----
 400   ****************6-----
 500   *************************5--------
 630   ************2--
 800   ************2----
  1K   ****************6------
 1.2   ***********1-
 1.6   ******************8----
  2K   ***************************7----
 2.5   ********************0-
 3.2   *****************7--
  4K   **************4-
  5K   ************2
 6.3   ***********1
  8K   ***********1
 10K   **********0
 12K   ***********1
 DBA   ********************************2---
       I    .    I    .    I    .    I    .    I    .    I    .    I    .    I    .    I    .    I
       0        10        20        30        40        50        60        70        80        90 DB
```

Fig. 6

```
F- AND T-TEST FOR NOISE MEASUREMENTS.            '+-*/ TEKNISK EDB, DANFOSS, NORDBORG.    PROGRAM M3062 /*-+'
  1 COMPRESSORS TYPE PW4.5K9  *  220 VOLT *  EVAPORATING TEMP. -25 C *   MF. DATE            * CODE  6
    1 SC.POS. 11 MIK.POS      *   50 HZ   *   CONDENSING  -*-   55 C *  MES.  -*- 03.06.72 * (REFERENCE)
LP*10 193 145 133 121 120 130 125 137 148 157 251 122 121 158 113 178 273 204 169 137 120 106 110  98 111 316
S     1.1 0.3 0.2 0.3 0.7 0.5 1.2 0.7 1.9 2.3 3.8 1.1 1.8 3.2 0.5 1.8 1.8 0.7 1.2 0.6 0.2 0.3 0.1 0.2 0.3 1.3
-------------------------------------------------------------------------------------------------------------
  1 COMPRESSORS TYPE PW4.5K9  *  220 VOLT *  EVAPORATING TEMP. -25 C *   MF. DATE            * CODE  7
  AS ABOVE. COMPR.MOVED 0.7 M *   50 HZ   *   CONDENSING  -*-   55 C *  MES.  -*- 03.06.72 *
LP*10 190 145 132 124 121 143 122 133 161 159 250 126 117 149 118 173 264 207 177 135 118 110 108  96 108 312
S     1.5 0.4 0.2 0.4 0.7 1.3 1.4 0.8 1.9 1.4 4.0 1.0 1.7 3.4 0.8 0.7 1.5 0.9 1.8 0.9 0.2 1.3 0.1 0.2 0.2 0.9

T*100 -62 -40 -45 161  18 294 -63-137 158  27  -7  92 -51 -63 178 -86-137  67 125 -39-209  95-358-204-283 -81
DEG.F  20  20  20  20  20  14  20  20  20  20  20  20  20  20  20  14  20  20  20  20  20  11  20  20  20  20
     HZ50  63  80 100 125 160 200 250 315 400 500 630 800  1K 1.2 1.6  2K 2.5 3.2  4K  5K 6.3  8K 10K 12K DBA
=============================================================================================================
 SPECTROGRAM FOR CALCULATED LP-MEAN. * =95 PCT, ** =99 PCT AND *** =99.9 PCT SIGNIFIC.  F ONLY 95 PCT TESTED.
     I DB REL. I  F=    5        10        15        20        25        30        35        40        45 DB     50
     I TO REF. I V/VMIN ' . . . . I . . . . ' . . . . I . . . . ' . . . . I . . . . ' . . . . I . . . . ' . . . . I
HZ50 I -0.3     I  1.88  ---------------------------IO
  63 I -0.1     I  2.15  ------------------0
  80 I -0.0     I '1.38  ----------------0
 100 I  0.3     I  1.38  -------------0+
 125 I  0.1     I  1.07  -------------0
 160 I  1.2*    I  6.65* ---------------0++
 200 I -0.3     I  1.27  -------------IO
 250 I -0.4     I  1.07  ---------------IO
 315 I  1.3     I  1.05  -------------------0+++
 400 I  0.2     I '2.67  --------------------0
 500 I -0.1     I  1.12  ---------------------------------------0
 630 I  0.4     I '1.31  -------------0+
 800 I -0.4     I '1.06  ------------IO
  1K I -0.9     I  1.11  -------------------IIO
 1.2 I  0.5     I  2.76  ------------0+
 1.6 I -0.5     I '6.29* ------------------------IO
  2K I -1.0     I '1.46  ------------------------------------------IIO
 2.5 I  0.2     I  1.63  ------------------------------0
 3.2 I  0.8     I  2.11  -----------------------0++
  4K I -0.1     I  2.52  ----------------0
  5K I -0.2*    I '1.17  -------------0
 6.3 I  0.4     I  ***** ----------0+
  8K I -0.1**   I  1.78  -----------0                            OBS.: FIVE ASTERISK: F>9.99
 10K I -0.2     I  1.94  ---------0
 12K I -0.3*    I '2.70  ----------IO
DBA  I -0.4     I '2.09  ---------------------------------------------------IO
              I . . . . ' . . . . I . . . . ' . . . . I . . . . ' . . . . I . . . . ' . . . . I . . . . ' . . . . I
```

Fig. 7.

```
F- AND T-TEST FOR NOISE MEASUREMENTS.            '+=*/ TEKNISK EDB, DANFOSS, NORDBORG.    PROGRAM M3062 /*-+'
 1  COMPRESSOR  TYPE PW4.5K9  *  220 VOLT *  EVAPORATING TEMP. -25 C *   MF. DATE            * CODE 11
   10 MEASUR. WITH 1 MIN.INTV.*   50 HZ   *   CONDENSING  -*-   55 C *  MES.  -*- 03.06.72 * (REFERENCE)
LP*10 196 145 131 121 117 136 110 140 142 154 240 111 107 115 107 171 259 195 161 131 120 105 108  97 112 302
S     1.1 0.2 0.2 0.2 0.2 0.3 0.2 0.6 0.3 0.4 0.9 0.3 0.1 0.4 0.3 0.7 1.5 0.5 0.5 0.2 0.2 0.5 0.1 0.1 0.1 0.9
-------------------------------------------------------------------------------------------------------------
  1 COMPRESSOR  TYPE PW4.5K9  *  220 VOLT *  EVAPORATING TEMP. -25 C *   MF. DATE            * CODE  6
    1 SC.POS. 11 MIK.POS      *   50 HZ   *   CONDENSING  -*-   55 C *  MES.  -*- 03.06.72 *
LP*10 193 145 133 121 120 130 125 137 148 157 251 122 121 158 113 178 273 204 169 137 120 106 110  98 111 316
S     1.1 0.3 0.2 0.3 0.7 0.5 1.2 0.7 1.9 2.3 3.8 1.1 1.8 3.2 0.5 1.8 1.8 0.7 1.2 0.6 0.2 0.3 0.1 0.2 0.3 1.3

T*100 -56  46 197  25 119-329 410-113 113  35  91 309 259 433 320 129 197 348 185 295 -37  25 450 138-122 284
DEG.F  19  19  19  16  11  19  11  19  11  11  12  12  10  10  16  14  19  19  14  14  19  19  19  19  16  19
     HZ50  63  80 100 125 160 200 250 315 400 500 630 800  1K 1.2 1.6  2K 2.5 3.2  4K  5K 6.3  8K 10K 12K DBA
=============================================================================================================
 SPECTROGRAM FOR CALCULATED LP-MEAN. * =95 PCT, ** =99 PCT AND *** =99.9 PCT SIGNIFIC.  F ONLY 95 PCT TESTED.
     I DB REL. I  F=    5        10        15        20        25        30        35        40        45 DB     50
     I TO REF. I V/VMIN ' . . . . I . . . . ' . . . . I . . . . ' . . . . I . . . . ' . . . . I . . . . ' . . . . I
HZ50 I -0.3     I '1.11  ----------------------------IO
  63 I  0.0     I  1.71  -------------------0
  80 I  0.2     I  1.12  ----------------0
 100 I  0.0     I  4.04* --------------0
 125 I  0.3     I  ***** --------------0+
 160 I -0.6**   I  3.28  ----------------IO
 200 I  1.5**   I  ***** ------------0+++
 250 I -0.3     I  1.58  -----------------IO
 315 I  0.7     I  ***** ------------------0+
 400 I  0.3     I  ***** ---------------------0+
 500 I  1.1     I  ***** --------------------------------------0++
 630 I  1.1**   I  ***** ------------0++
 800 I  1.4*    I  ***** -----------0+++
  1K I  4.2**   I  ***** -------------0++++++++               OBS.: FIVE ASTERISK: F> 9.99
 1.2 I  0.6**   I  4.03* -----------0+
 1.6 I  0.7     I  6.78* ------------------------0+
  2K I  1.5     I  1.40  ------------------------------------------0+++
 2.5 I  0.9**   I  2.21  -----------------------------0++
 3.2 I  0.7     I  7.00* ----------------------0+
  4K I  0.6*    I  7.22* ----------------0+
  5K I -0.0     I  1.23  --------------0
 6.3 I  0.0     I '2.45  -----------0
  8K I  0.1***  I  1.64  ------------0
 10K I  0.1     I  2.25  ---------0
 12K I -0.1     I  4.05* ------------0
DBA  I  1.4*    I  2.35  --------------------------------------------------0+++
              I . . . . ' . . . . I . . . . ' . . . . I . . . . ' . . . . I . . . . ' . . . . I . . . . ' . . . . I
```

Fig. 8.