Measurement of the noise emission of machine tools

"Machinery" Directive

The Directive 2006/42/EC of the European Parliament and of the Council, published on May 17th, 2006, known as "Machinery" Directive, contains in its Annex 1, "Essential health and safety requirements relating to the design and construction of machinery", the subclause 1.7.4.2. "Contents of the instructions" which reads:

"Each instruction manual must contain, where applicable, at least the following information:

and, in particular, in point 1.7.4.2 u):

the following information on airborne noise emissions:

— the A-weighted emission sound pressure level at workstations, where this exceeds 70 dB(A); where this level does not exceed 70 dB(A), this fact must be indicated,

— the peak C-weighted instantaneous sound pressure value at workstations, where this exceeds 63 Pa (130 dB in relation to 20 μPa),

— the A-weighted sound power level emitted by the machinery, where the A-weighted emission sound pressure level at workstations exceeds 80 dB(A).

These values must be either those actually measured for the machinery in question or those established on the basis of measurements taken for technically comparable machinery which is representative of the machinery to be produced.

In the case of very large machinery, instead of the A-weighted sound power level, the A-weighted emission sound pressure levels at specified positions around the machinery may be indicated."

The manufacturer or his authorised representative in the EU territory, shall then know and declare the noise emission levels of the machine tool.

International Standard ISO 230-5

Since 1977 the Italian standard UNI 7712 was existing in Italy, drafted by the STANIMUC working group "Noise", made up of high level acoustic experts, belonging to research laboratories, universities and industry.

And since that time STANIMUC was carrying out, on request of several machine tool manufacturers, noise tests not less accurate and complete than they are nowadays.

But the same work had to be done at international level as well, i.e. drafting an International Standard containing in one and only paper all what is needed for performing an accurate noise test, removing those parts of the basic ISO acoustic standards which are redundant or not fitting requirements and characteristics of the machine tool sector.

With this target Sub-Committee SC 6 "Noise" was set up within the Technical Committee ISO/TC 39 "Machine tools", and STANIMUC took over the relevant Chair, Secretariat and the task of drafting the first proposal.

During the nineties, shortly after the first version of the "Machinery" Directive 89/392/EC was published, a standard was drafted for fitting those requirements, and the first version of ISO 230-5 "Test code for machine tools – Part 5: Determination of the noise emission" was eventually published in 2000, and is still in force, although under revision.

State of the art

From the experience gained through several hundreds of noise tests carried out in the years, data are today available for a statistical assessment of the state of the art in the field of machine tools, in particular on the following items:

- ability of manufacturers to build machines acceptable from the acoustic point of view, in terms of:
  - time-averaged emission sound pressure level in dB(A) in the work station
  - C-weighted peak emission sound pressure level in dB(C) in the work station
  - surface sound pressure level in dB(A)
  - sound power level
- fitness of industrial environments for noise tests, in terms of:
  - environmental correction K_{2A}
  - ratio A/S.

In particular, data used for this paper come from 100 noise tests of machine tools, most of which metal-cutting. Their values are hereunder reported by means of histograms, percentages and percentiles, for ease of reading and understanding.

Objective limits of this assessment are in the operating conditions, which have been selected, as specified in ISO 230-5, "*in a manner which is typical of normal use*", but each and every machine tool can carry out several different operations, and the reported results relate to one only. Each machine can produce, during its working life, different noise emissions depending on the current operating conditions.

Time-averaged emission sound pressure level in the operator's position in dB(A)

The first information required by the Directive is "*the A-weighted emission sound pressure level at workstations, where this exceeds 70 dB(A)*". The manufacturer or his authorised representative in the EU territory shall know and declare this figure.

"Time-averaged" is the sound pressure level of a continuous steady sound that, within a measurement time interval, has the same mean square sound pressure as the variable noise under consideration.

Moreover, "A-weighted" means that the measured noise is processed in the sound level meter by filters giving more value to frequencies where the human ear is more sensitive and less value to frequencies at the edges where the ear is less sensitive. Measured levels are then expressed in dB(A).

Histogram in figure 1 provides values of the A-weighted emission sound pressure levels measured at the workstations of the 100 machines of the sample.

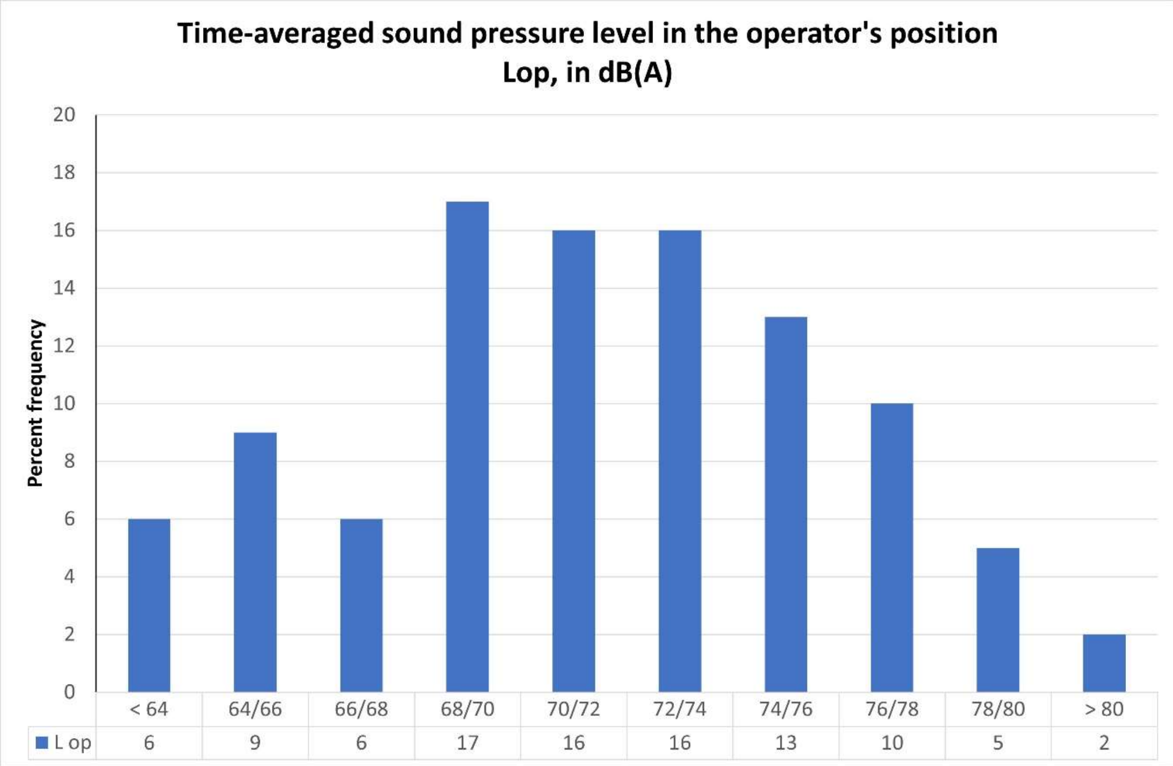

Figure 1 – Time-averaged sound pressure level in the operator's position

L op	< 64	64/66	66/68	68/70	70/72	72/74	74/76	76/78	78/80	> 80
percentile	6	15	21	38	54	70	83	93	98	100

Only two machines out of one hundred, in the actual operating conditions of the measurement, emitted an equivalent sound pressure level in the operator's position exceeding 80 dB(A), requiring, according to the Directive, the determination of the sound power level as well (which has been anyway determined for all 100 machines of the sample).

In 60 cases the manufacturer would be allowed to declare only the equivalent sound pressure level in the operator's position. In 38 cases the manufacturer might even declare that the sound pressure level is lower than 70 dB(A), without providing values.

C-weighted peak emission sound pressure level in the operator's position

C-weighting filters of a sound level meter provide a flat response in the frequency range from 200 to 1250 Hz, corresponding to the central part of the audible range. The C-weighted peak emission sound pressure level provides an assessment of the risk of hearing damage due to an impulsive noise.

It is not even necessary to produce a histogram, as the machines of the sample have seldom emitted a peak sound pressure level exceeding 100 dB(C). The Directive considers "*130 dB in relation to 20 μPa*" as an alert threshold, corresponding to 63 Pa.

The table hereunder, showing the correlation between the sound pressure level measured and the physical pressure in pascals, proves that a 100 dB(C) sound pressure level corresponds to a physical pressure 32 times lower than the threshold specified by the Directive.

dB	94	100	106	112	118	124	130
pascals	1	2	4	8	16	32	63

For all the measured machines the manufacturer might simply declare that the peak sound pressure level is lower than 130 dB(C).

Surface sound pressure level in dB(A)

First the reference box is to be defined, as the smallest rectangular parallelepiped that just encloses the source and terminates on the floor. The reference box shall disregard elements protruding from the source that are not significant radiators of sound energy, but shall include all the auxiliary equipment in operation during the noise test.

The measurement surface is then a hypothetical rectangular parallelepiped whose sides are parallel to those of the reference box and spaced out a distance of 1 m. The surface sound pressure level is the average of all pressure levels measured in the n microphone positions on the measurement surface, where n depends upon the size of the surface.

Bearing in mind that the sound pressure level is a logarithm, the average is obtained by determining from each pressure level its physical quantity (pascals or W/m^2), and by determining later the logarithm of the average value of the physical quantities.

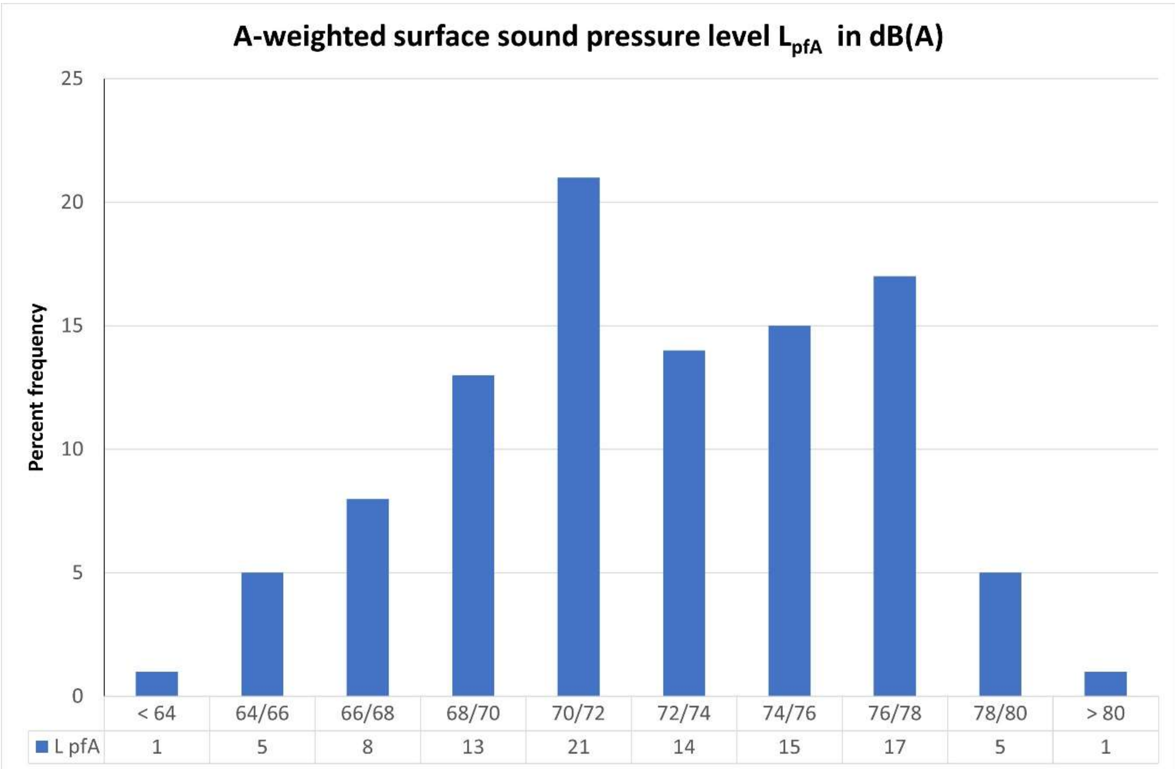

Figure 2 – A-weighted surface sound pressure level

L pfA	< 64	64/66	66/68	68/70	70/72	72/74	74/76	76/78	78/80	> 80
percentile	1	6	14	27	48	62	77	94	99	100

The surface sound pressure level is an average, as of course all measured levels are different from each other in the various microphone positions, depending on the location of the individual sound sources of the machine itself and of the auxiliary equipment.

However, its determination is required for calculating the emission sound power, i.e. the rate per unit time at which the overall airborne sound energy is radiated.

Sound power level in dB(A) and sound power in mW

The sound power is calculated by multiplying the sound intensity in W/m^2 by the area of the measurement surface in m^2, and consequently the sound power level is obtained by summing up the relevant logarithms.

One only surface sound pressure level of the sample exceeded 80 dB(A), but the eventual sound power level of the 100 machines has always resulted between 80 and 110 dB(A), which frightens most of the people reading these values.

Actually, although these values too are expressed in dB(A), they are not sound levels as perceived by the human ear (sound pressure levels), but calculated values (sound power levels), useful for assessing the overall sound energy per unit time immitted in an environment where many machines are installed.

It may be advisable to express these values in milliWatts and Watts, rather than in dB(A), which may be misunderstood.

L_{WA}	90 dB	100 dB	110 dB	120 dB	130 dB	140 dB	150 dB
WA	1 mW	10 mW	100 mW	1 W	10 W	100 W	1 kW

Taking into account that a jet aircraft can radiate a sound power of about 1kW, corresponding to 150 dB, it is easy to understand that the machine tools measured radiate in comparison a sound power of about some millionths of the kW.

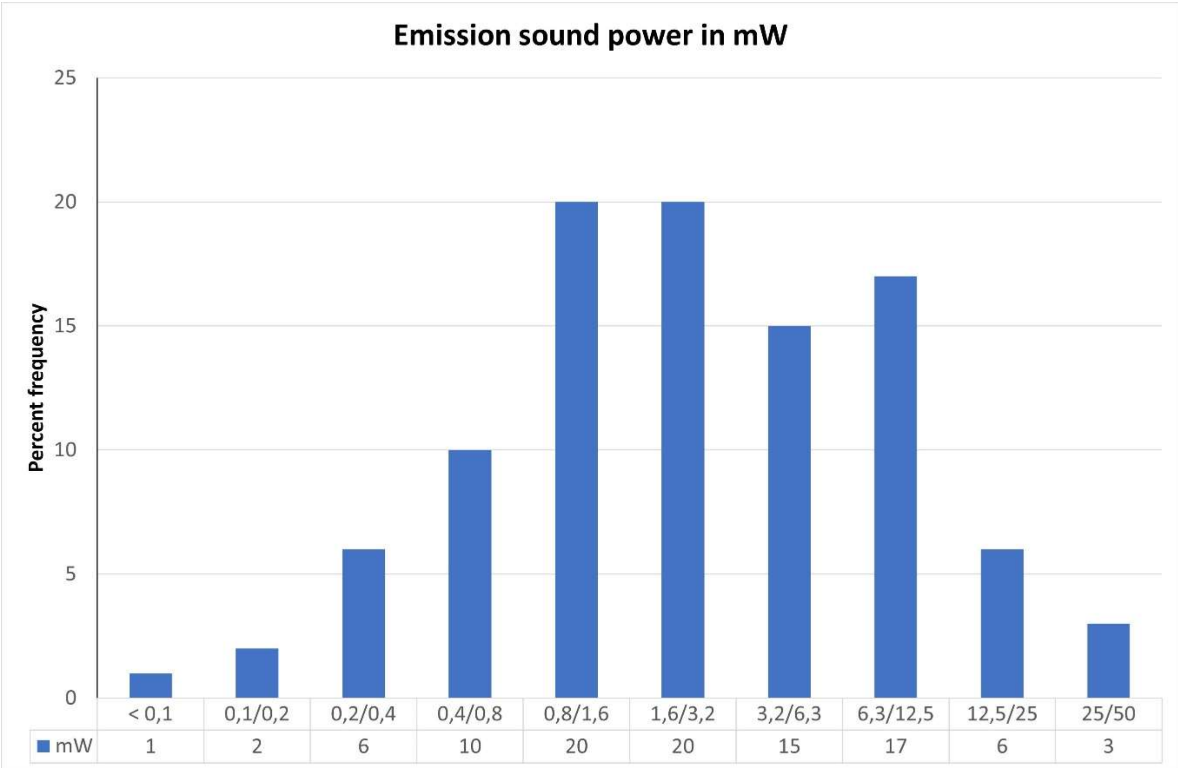

Figure 3 – Emission sound power

mW	< 0,1	0,1/0,2	0,2/0,4	0,4/0,8	0,8/1,6	1,6/3,2	3,2/6,3	6,3/12,5	12,5/25	25/50
percentile	1	3	9	19	39	59	74	91	97	100

Test environment

Some questions are left about the qualification of the industrial environments for running noise tests, i.e. whether the environmental reverberation allows for reliable measurements, or to which extent they shall be corrected. Answers are provided by the environmental correction K_{2A} and the parameters used for its determination.

Figure 4 shows the distribution of the K_{2A} value, which in the ISO standards is properly considered as a main contributor for meeting the requirements of grade 2 accuracy (engineering method) or grade 3 accuracy (survey method), respectively if it is lower than 2 dB(A) or between 2 and 7 dB(A). It should be taken into account that grade 1 (precision method) can be obtained in hemi-anechoic room, therefore it is not even mentioned in ISO 230-5.

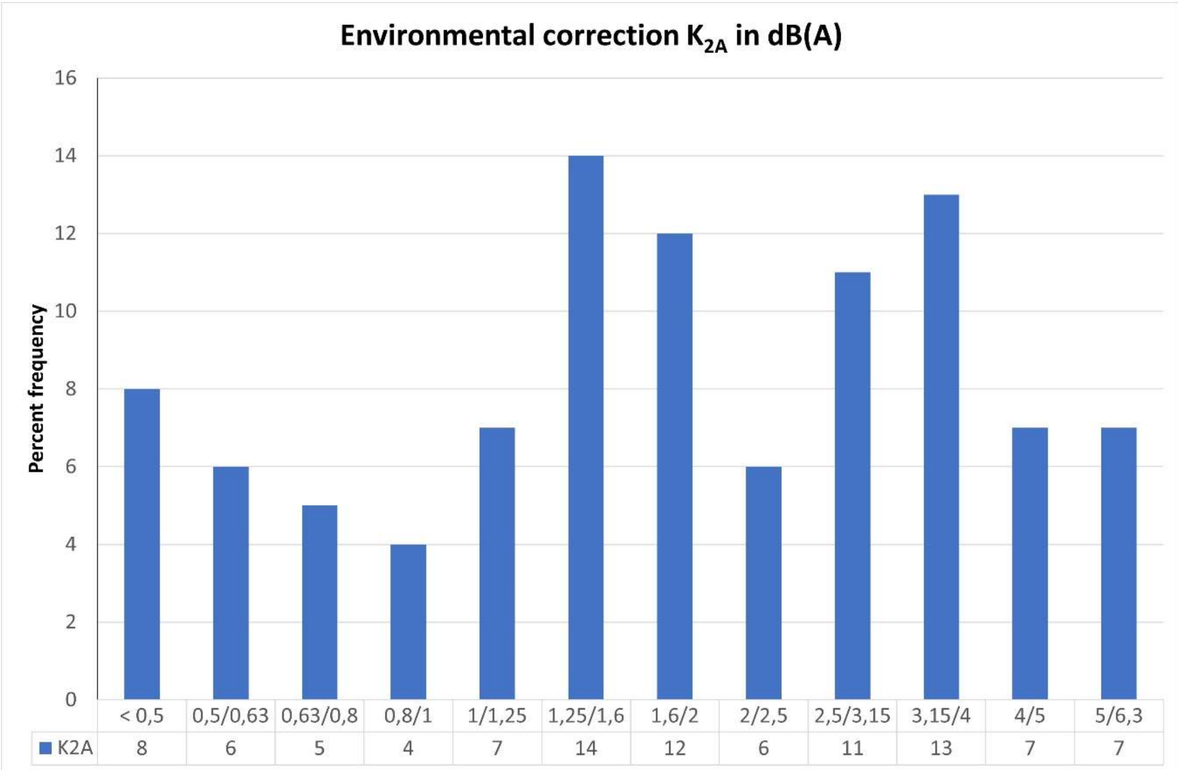

Figure 4 – Environmental correction K_{2A}

K2A	< 0,5	0,5/0,63	0,63/0,8	0,8/1	1/1,25	1,25/1,6	1,6/2	2/2,5	2,5/3,16	3,16/4	4/5	5/6,3
percentile	8	14	19	23	30	44	56	62	73	86	93	100

The histogram here above shows that for the 56% of the measured machines the environment enabled to achieve grade 2 accuracy (K_{2A} < 2), and in the 44% grade 3 accuracy. The correction K_{2A} proved to be always lower than 7 dB(A).

Although the procedure using a reference sound source is preferred, on machine tools it is almost never possible to correctly place a reference sound source and to accurately determine L^*_{WA}. In this case other procedures are to be used, as described hereunder.

A basic component for the determination of K_{2A} is the ratio A/S between the "equivalent sound absorption area" A and the area of the measurement surface S. The value of A, in square meters, can be determined by two different methods.

The first method requires the measurement of the reverberation time of the test room which is excited by an impulsive sound (as for instance by shooting a starter's gun). The value of A is given, in square meters, by the expression

$A = 0{,}16\ V/T$

where

V is the volume of the test room, in cubic meters

T is the reverberation time of the test room, in seconds.

This method has been adopted in most cases, with the only exception of circumstances where shooting a starter's gun was forbidden.

By the second method, approximate, the value of A is given, in square meters, by the expression

$A = \alpha\ S_V$

where

α is the mean sound absorption coefficient, given in the table hereunder

S_V is the total area of the boundary surfaces of the test room (walls, ceiling and floor), in square meters.

Mean sound absorption coefficient α	**Description of room**
0,05	Nearly empty room with smooth, hard walls made of concrete, brick, plaster or tile
0,1	Partly empty room, room with smooth walls
0,15	Room with furniture; rectangular machinery room; rectangular industrial room
0,2	Irregularly shaped room with furniture; irregularly shaped machinery room or industrial room
0,25	Room with upholstered furniture; machinery or industrial room with a small amount of sound-absorbing material on ceiling or walls (for example, partially absorptive ceiling)
0,35	Room with sound-absorbing materials on both ceiling and walls
0,5	Room with large amounts of sound-absorbing materials on ceiling and walls

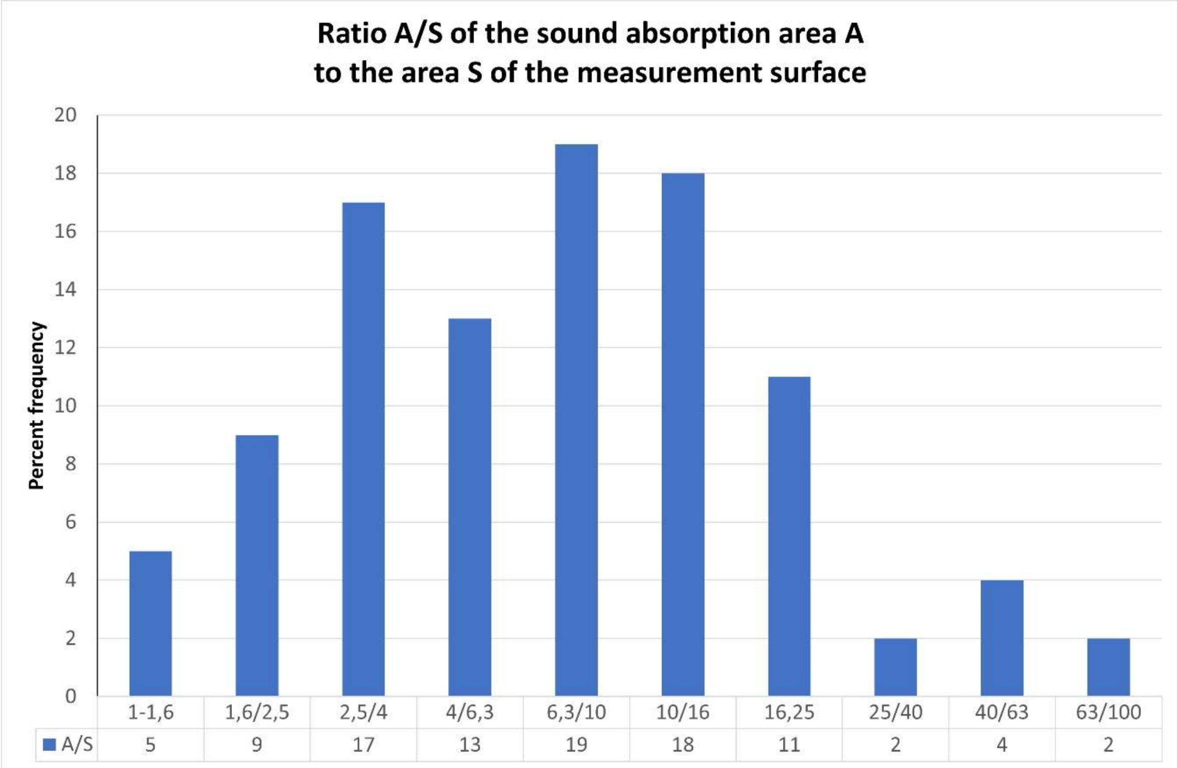

Figure 5 – Ratio A/S

A/S	1/1,6	1,6/2,5	2,5/4	4/6,3	6,3/10	10/16	16/25	25/40	40/63	63/100
percentile	5	14	31	44	63	81	92	94	98	100

For the measurement surface in a test room to be satisfactory for measurements in accordance with the requirements of ISO 230-5, the ratio of the sound absorption area A to the area S of the measurement surface is to be equal to or greater than 1, that is:

$A/S \geq 1$.

The larger the ratio A/S is, the better.

If the above requirement cannot be satisfied, a new measurement surface shall be chosen. The new measurement surface shall have a smaller total area, but shall still lie outside the near field. Alternatively, the ratio A/S may be increased by introducing additional sound-absorbing materials into the test room and then redetermining the value of the ratio A/S under the new conditions.

However the histogram in figure 5 shows that in all noise tests of the sample the ratio A/S resulted greater than 1, often by far greater than 1. Consequently, the industrial environments, where the measurements have been carried out, often allowed to obtain fairly reliable results which, as shown also by the values of K_{2A}, achieved grade 2 accuracy in more than 50% of cases.