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DETERMINATION OF UNCERTAINTY OF A REFERENCE PRESSURE TRANSDUCER TRANSFER FUNCTION IN FREQUENCY BELOW 100 HZ

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Abstract. *This work shows the application of the methodology of the calculation of uncertainty, using the NF ENV 13005 (ISO GUM) standard, for the dynamic calibration of a reference pressure transducer according to a frequency band of 1 to 100 Hz. Implementing dynamic calibration requires different operations in order to determine the information required for calculating uncertainty in the transducer, as well as in the whole process of acquisition and treatment.*

Keywords*: Dynamic calibration, pressure transducer, uncertainty, GUM*

1. Introduction

In the domain of the static calibration of pressure transducers, use is made of pressure standards such as the pressure gauge and Manometer balance. These standards are "traceable" to the basic fundamental quantity or derivatives, and the calculations of uncertainties belong to the public domain. They allow us to have worldwide intercomparisons of static calibration between different methods and in a great number of laboratories.

In the domain of the dynamic calibration of pressure transducers, there is not a dynamic pressure standard (eg a step pressure standard or a sinus pressure standard). By the traditional methods, it is not possible metrologically to trace “dynamic pressure standard” to the fundamental or derived standard “static”. In this situation, a calculation of uncertainty on the input of the transducer to be calibrated is not easy to attain. In the literature, one can see that, whatever the means of calibration used, periodic or non-periodic, a reference transducer, or that which is supposed to be one, is always necessary. Even if interesting calculations of uncertainty are proposed, they are always incomplete. In particular, the domain of frequency/time has not specified what is fundamental in the dynamic domain

In order to resolve this problem, in the 7th international congress of metrology in Nimes, Damion proposed a methodology adapted to the dynamic calibration of reference pressure transducers. (1995)

2. Method

A pressure transducer is chosen, among the commercial sensors, according to its metrological features. Static and dynamic linearity is essential. There must be as little influence of external parameters as possible, in particular as regards acceleration and temperature. The bandwidth and the resonance frequency announced are naturally compatible with the field of frequency considered.

After calibration in quasi-static mode, the sensor is submitted to degrees of pressure of equivalent amplitude using step generators covering an adapted field of frequency. The output *S (T)* is recorded and used to determine the transfer function *H (F)*. By the same means, the tests are repeated in order to evaluate to what extent they are repeatable.

In the case of the quasi-static calibration, the input level in tension or pressure is measured with calibrated instruments traceable to the static references and used in stabilized modes.

For the dynamic calibration, the input not being available, the transfer function cannot be calculated. However, it is possible to estimate a transfer function between an ideal entry (perfect input) and the measured output. The transfer function estimated reveals a difference (Figure 1) between the ideal transfer function and the one measured. The latter function is nearer to the unit, as the elements of the chain are better. This transfer function is total and represents the imperfections of the step generator, associated electronics, pressure transducer, acquisition system and treatment. The transfer function does not enable one to have information about the source of the defects found in the response of the sensor.

The maximum deviation is ε for a frequency bandwidth [f1, f2] for example. It is considered that this variation ε is the maximum error in the bandwidth [f1, f2]. This error depends to a large extent on the step generator and cannot be corrected. This is taken into account in the calculation of uncertainty in the form of an uncertainty-type by supposing a rectangular distribution.

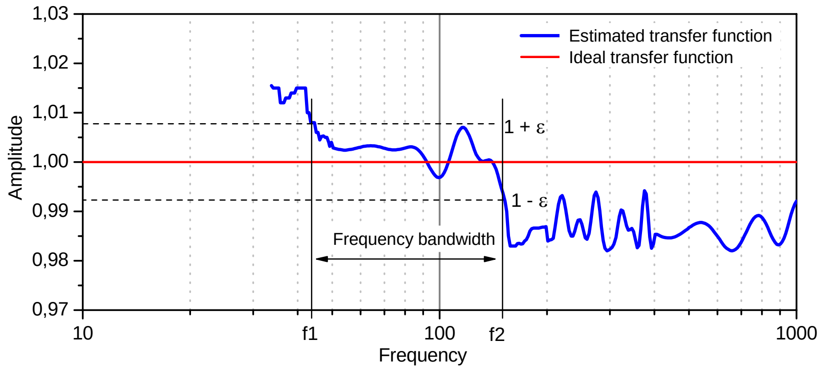

Figure 1 - Principle of the dynamic calibration - ideal and estimated transfer function

In practice, a single calibration device does not cover a sufficient frequency range to meet requirements. It is thus necessary to associate several calibration devices to increase the frequency band. In the case of low frequency calibration, the implementation of the method requires only one step pressure generator.

3. Implementation of the dynamic calibration

The implementation of the dynamic calibration for a reference transducer requires some operations. The different phases are necessary to calculate uncertainty for the transducer, the chain of acquisition and the treatment.

The principal phases are:

- quasi-static calibration in tension of the acquisition chain
- quasi-static calibration in pressure of the reference transducer
- dynamic calibration of the acquisition chain
- dynamic calibration of the reference transducer.

3.1. Quasi-static calibration of the acquisition chain

The acquisition chain or acquisition system is composed of a low-pass filter and a recorder of transients. A degree of voltage is applied at the input of the acquisition chain and a multimeter by using the step generator GE01 [2].

The multimeter provides the amplitude of the level **D**U of entry. After acquisition and recording of the transitory answer, the software KETSTA gives **D**V at the output of the acquisition chain

The various ranges of measurement and the various channels are calibrated. The procedure of calibration prescribes five repeated levels of tension four times.

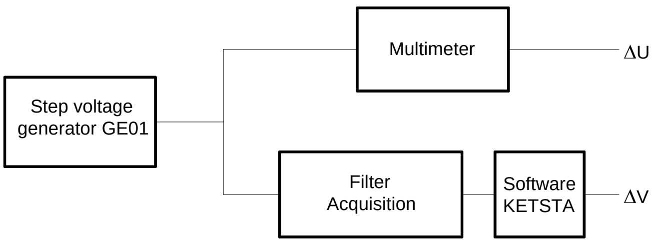

Figure 2 - Quasi-static calibration in tension

The causes of errors are shows in table 1

Sources	Type	Value [V]	Dist. Prob.	Div.	Uncert. [V]
Calibration of the multimeter	B1	1,70E-04	Normal	2,00	1,2E-04
Variation of measurements	B2	2,65E-03	Triangle -rectangle	4,24	6,2E-04
Temporal drift of the multimeter	B3	3,50E-04	Rectangle	1,73	2,0E-04
Resolution of the multimeter	B4	0,0001	Rectangle	3,46	4,1E-05
Rounded treatment (KETSTA)	B5	1,00E-04	Rectangle	3,46	4,1E-05
Measure level	B6	1,46E-04	Normal	2,00	1,0E-04
Dispersion of measurements	A1	4,22E-05		2,00	2,1E-05
Combining uncertainty			Normal	Mult.	6,7E-04
Expanded uncertainty			**Normal**	**2,00**	**1,3E-03**

Table 1 - Calculation of uncertainty into quasi-static of the acquisition system

3.2. Result of the calculation of uncertainty

Figure 3 illustrates the weight of each component in the estimate of uncertainty. The difference between the measure and the standard is the principal source of uncertainty, as this is an error of accuracy. It can be minimized by fitting the acquisition chain, into or replacing it by, a more powerful chain.

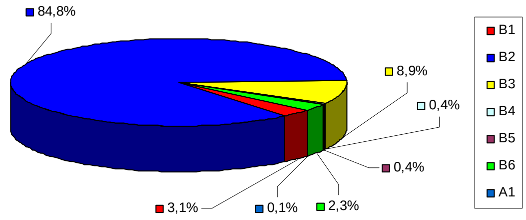

Figure 3 - Distribution of the weight of the sources of uncertainties in channel 01 of the acquisition chain

3.3. Quasi-static calibration of the reference pressure transducer

A step pressure is applied to the input of the acquisition chain (transducer, associated electronics, filter and recorder of transient) using fast opening device DOR20 [Damion, 2003]. Two pressure gauges are used for the pressure control in the small chamber and the large chamber.
The pressure gauge installed on the small chamber provides the amplitude of the input step pressure ΔP. After acquisition and recording of the transitory output, the software KETSTA gives ΔV at output of the acquisition chain.

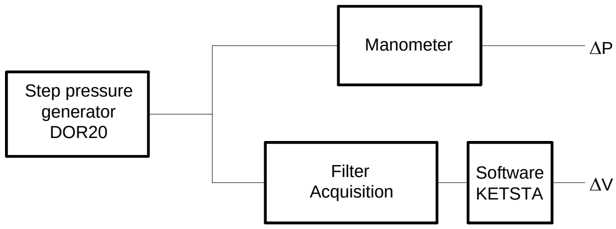

Figure 4 – Quasi-static Calibration in pressure

This operation is carried out on the reference transducer for five values in amplitude and is repeated four times for each point.
The sources of errors are shown in table 2

Sources	Type	Value [Pa]	Dist. Prob.	Div.	Uncert. [Pa]
Calibration of the pressure gauge	B1	59	Normal	2,00	42
Quasi static calibration of the acquisition system	B2	129	Normal	2,00	91
Temporal deviation of the pressure gauge	B3	100	Rectangle	1,73	58
Thermal deviation of the pressure gauge	B4	100	Rectangle	1,73	58
Reading of the pressure gauge	B5	10	Rectangle	3,46	4
Measure level	B6	84	Triangle	2,45	49
Rounded treatment (KETSTA)	B7	10	Rectangle	3,46	4
Error of modeling	B8	35		1,00	35
Dispersion of measurements	A1	87		2,00	43
Combining uncertainty				Mult.	149
Expanded uncertainty			**Normal**	**2,0**	**298**

Table 2 - Calculation of uncertainty in quasi-static of a pressure transducer of reference

3.4. Results of quasi-static calibration of a sensor of reference

The results presented are those of a piezoelectric transducer evaluated for its use as a sensor of reference.

The modeling of the sensitivity in pressure is obtained by the method of least squares.
The weight of uncertainty due to the acquisition system is the most significant part of uncertainty in quasi-static modes. The whole of the components of the calibration method used corresponds to approximately 25% of the value of uncertainty. Figure 5 illustrates the distribution of weight of the actuating quantities taken into account in the calculation of estimate uncertainty.

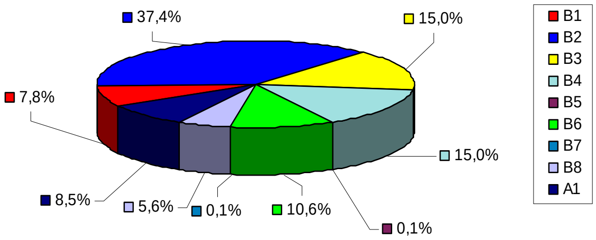

Figure 5 - Distribution of the weight of the sources of uncertainties into quasi-static in pressure.

4. Dynamic calibration of the acquisition system

A degree of tension is applied to the entry of the acquisition chain (filter and transient recorder) using the step generator GE01.

After acquisition and recording of the transitory output, the transfer function *H (F)* is calculated by the software EDYCAP.

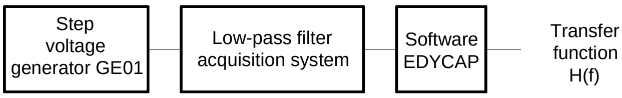

Figure 6 - Dynamic calibration of the acquisition system.

This operation is repeated for each channel of acquisition, for only one amplitude and it is repeated four times for each configuration of data records.

The Software EDYCAP calculates the transfer function with a resolution in frequency of 400 points. The cause of the errors is shown in table 3.

Sources (90Hz)	**Type**	**Value [V]**	**Dist. Prob.**	**Div.**	**Uncert. [V]**
Quasi static calibration of the acquisition system	B1	0,0013	Normal	2,0	0,0007
Error modeling variation	B2	0,0018	Rectangle	1,7	0,0010
EDYCAP	B3	0,0016	Normal	2	0,0008
Dispersion of measurements	A1	0,0003		2,0	0,0001
Combining uncertainty			Normal	**Mult.**	0,0015
Expanded uncertainty			Normal	2,0	**0,0029**

Table 3 - Calculation of uncertainty in dynamics of the system of acquisition to 90Hz

4.1. Quasi-static calibration in tension (B1)

The expanded uncertainty of calibration, with a correction factor K = 2, is obtained by means of the preliminary calibration of the acquisition system.

4.2. Transfer function (amplitude) (B2)

This uncertainty is obtained from the difference between the ideal transfers functions and the one which is measured. For each of the 400 values of the amplitude ratio of the transfer function, one calculates the deviation from the average transfer function of four measurements. Figure 7 represents the estimate of this variation.

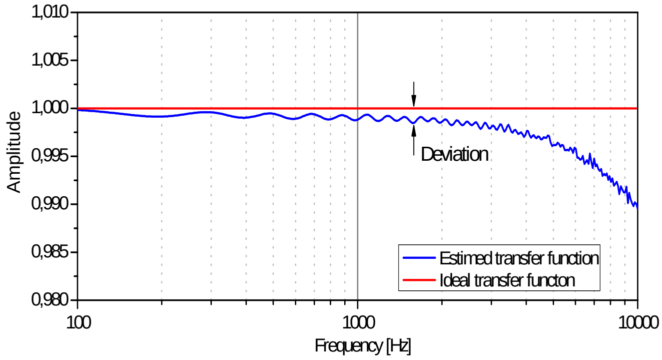

Figure 7 - Determination of the deviation of the transfer function (amplitude)

Standard uncertainty is calculated by making the consideration of a rectangular distribution.

4.3. Exploitation (EDYCAP) (B3)

The expanded uncertainty of the calibration, with a correction factor K = 2, is obtained by the procedure of evaluation and validation of the software EDYCAP. The value of expanded uncertainty calibration is obtained of the procedure of evaluation and validation of the software EDYCAP.

4.4. Uncertainties of repeatability (A1)

The uncertainty due the repeatability is calculated from the standard deviation of four measurements for the 400 values of amplitude ratios of the transfer function.

4.5. Results of dynamic calibration of the acquisition system

The low frequency calibration uses the period of sampling and the adjustment of the low-pass filter pre-established for the tests on the fast opening device (DOR20).

The amplitude of the transfer function of the acquisition system presents attenuation due to the response of the anti-aliasing filter (Figure 8). The sampling rate used is high enough to not create distortions of the signal.

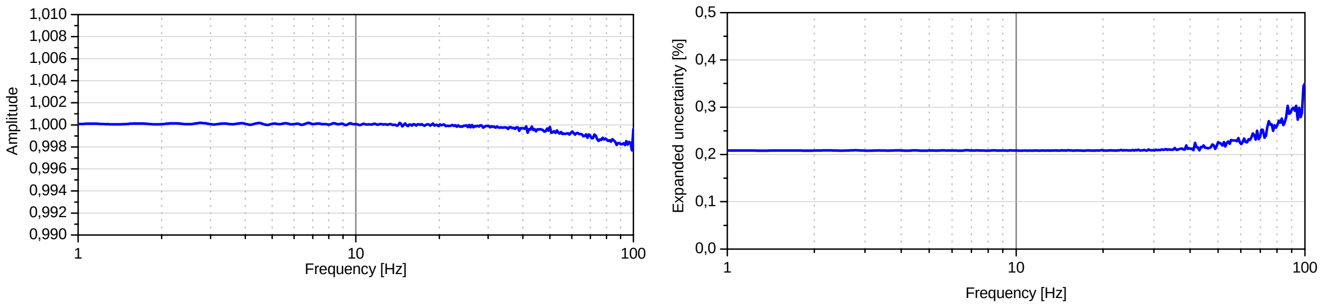

Figure 8 - Transfer function of the acquisition system (amplitude) and Estimate of the expanded uncertainty between 1-100Hz

The effect of the quantities active on the calibration is illustrated in figure 9. The observation of the distribution weights of the uncertainty sources shows: The calculation of the transfer function is dominating in the budget uncertainty.

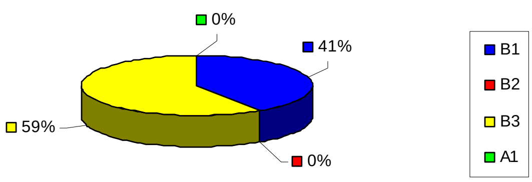

Figure 9 - Distribution weight of the uncertainty sources of a dynamic calibration of the acquisition system in 1Hz

However, in Figure 10 the distribution weights are different at the frequency 50Hz. This is explained by the influence of the noise of the electrical supply network.

Figure 11 illustrates the distribution of weight uncertainties with 50 Hz and shows that the error of repeatability increases appreciably. This is due to the random effect of the noise generated generated by the electrical supply network.

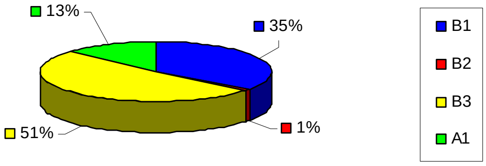

Figure 10 - Distribution weight of the uncertainty sources of a dynamic calibration of the acquisition system at 50Hz

The weight of repeatability is lower than 1% for the frequency of 90Hz. That confirms the influence of the electric noise as causing an increase in uncertainty at 50 Hz.

The graphic illustration of figure 11 reveals the increase in the error of modeling of the deviation. This is due to the effect of adjustment of the anti-aliasing filter of the acquisition system.

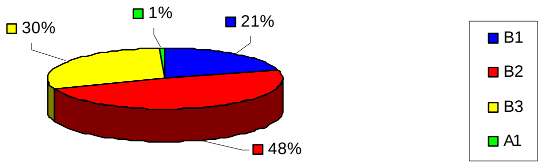

Figure 11 - Distribution weight of the uncertainty sources of a dynamic calibration of the acquisition system in 90Hz

5. Dynamic calibration of the reference pressure transducer

A step of pressure is applied at the input of the transducer followed by its associated electronics and of the chain with acquisition (filter and recorder of transient). To generate step pressure a fast opening device DOR20 is used. Figure 12 schematically represents the dynamic calibration of a reference pressure transducer at low frequency and the fast opening device DOR20. After acquisition and recording of the transitory output, the transfer function *H (F)* is calculated by the software EDYCAP.

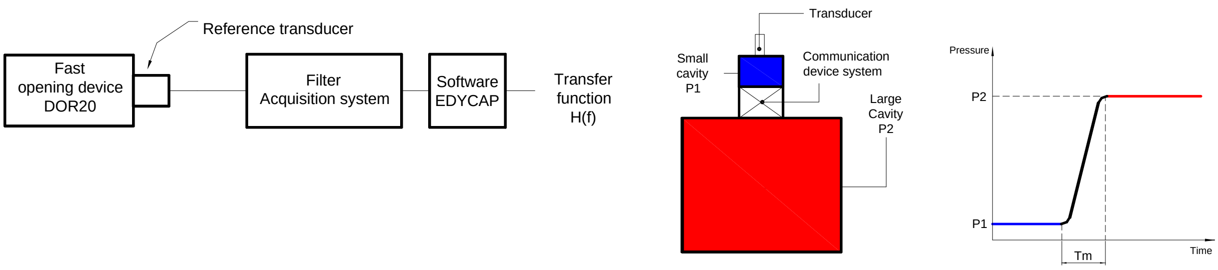

Figure 12 - Dynamic calibration of a reference pressure transducer

The transfer function is calculated by the software EDYCAP with a resolution in frequency of 400 points. The causes of errors are shows in table 4.

Sources (10Hz)	Type	Value [Pa]	Dist. Prob.	Div.	Uncert. [Pa]
Quasi static calibration of the pressure transducer	B1	298	Normal	2,0	149
Error modeling variation	B2	1005	Rectangle	1,7	580
Quasi static calibration of the acquisition system	B3	132	Normal	2,0	66
Dynamic calibration of the acquisition system	B4	929	Normal	2,0	465
Dispersion of measurements	A1	135		2,0	67
Combining uncertainty			Normal	**Mult.**	764
Expanded uncertainty			Normal	2,0	**1528**

Table 4 - Calculation of uncertainty in dynamics of the reference pressure transducer in 10Hz

Different factors are considered in groups, for example the type of gas used in the big and the small chamber of the fast opening device, and the connection system of two chambers. All these parameters are considered indirectly in the estimate of uncertainty, since it has a systematic influence on the variation of the transfer function (Oliveira, 2004).

5.1. Sources of uncertainties of the dynamic calibration Uncertainty of repeatability (A1)

As in the case of the dynamic calibration of the acquisition chain, there are 400 values calculated of repeatability. The values are related to the unit of pressure by the modeling of sensitivity obtained during the quasi-static calibration.

5.2. Uncertainty due to the quasi-static calibration of the reference pressure transducer (B1)

It is obtained of the preliminary calibration quasi-static of the reference pressure transducer.

5.3. Transfer function (amplitude) (B2)

This uncertainty is obtained from the difference between the ideal transfer functions and the one measured. For each of the 400 values of the amplitude ratio of the transfer function, the variation is calculated from the average transfer function of four measurements. Standard uncertainty is calculated supposing a rectangular distribution.

5.4. Quasi-static calibration of the acquisition system (B3)

It is obtained for the quasi-static calibration in voltage of the acquisition system.

5.5. Dynamic calibration of the acquisition system (B4)

Uncertainty is provided by the dynamic calibration of the acquisition chain. For each frequency of the transfer function calculated, there is a specific value of estimates of this uncertainty component.

5.6. Result of the dynamic calibration of a reference pressure transducer

Figure 13 shows the transitory output for response time obtained with the DOR20.

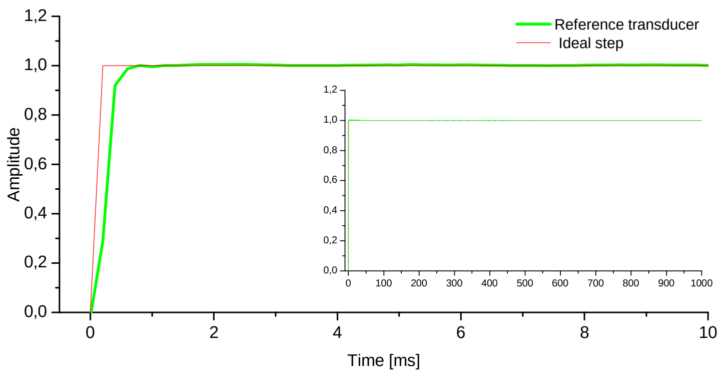

Figure 13 - Temporal response curve in the DOR20

The amplitude ratio of the transfer and estimate of expanded uncertainty function, for a reference pressure transducer, are presented in figure 14.

After 100Hz, the amplitude ratio of the transfer function, obtained by using the DOR20, attenuates over unit value. This is due to the rise time of the step pressure generated by the fast opening device.

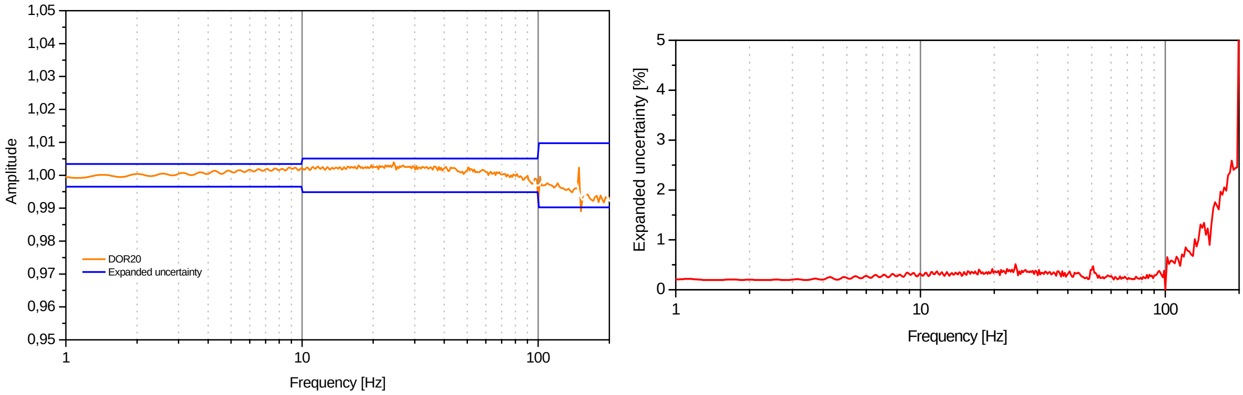

Figure 14 – Transfer function of the reference pressure transducer and expanded associated Uncertainty

Table 5 shows the final result of the estimated uncertainty according to the frequency in term of pressure and percentage.

Frequency band	Expanded Uncertainty [%]	Expanded Uncertainty [kPa]
1Hz with 10 Hz	0,35	1,7
>10 Hz to 49 Hz	0,51	2,6
>49 Hz to 100 Hz	0,51	2,5
>100 Hz to 130 Hz	1,0	5,0

Table 5 - Associated uncertainty of the reference pressure transducer.

6. Conclusion

With this study, step has been taken for the dynamic calibration of a reference pressure transducer at low frequency as well as the development of the method of estimate the associated uncertainty. This approach is based on the features of the fast opening device (DOR20), the acquisition systems and treatment of the Laboratory of Dynamic Metrology (ENSAM Paris) used with associated procedures.

The use of a reference pressure transducer on a step generator now makes it possible to implement a method of calibration by comparison. The corresponding calculation of uncertainty shows that, overall, expanded uncertainty in the case of this method does not increase in a significant way.

Within the framework of this communication, the frequency bandwidth is relatively restricted. It can be extended towards the high frequencies, by associating several step pressure generators (fast opening device and shock tubes).

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