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The Dynamic Characteristics of Some Low Pressure Transducers

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THE DYNAMIC CHARACTERISTICS OF SOME LOW PRESSURE TRANSDUCERS

by

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Synopsis

A test rig has been developed to produce sinusoidally varying pressures over a frequency range 0 to 1 kHz. This rig has been used to compare the dynamic performance of examples of various transducer types and, in particular, to measure the dynamic calibration factors of the low pressure Gaeltec transducers used in the Civil Engineering Department wind tunnels. Performance curves are presented.

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1. INTRODUCTION

Static calibration of transducers is simple to perform and is often assumed to hold under dynamic conditions. To verify this assumption (as a preliminary to their use for dynamic force measurement) a dynamic test rig has been developed so that the performances of various transducers can be compared at frequencies up to 1 kHz.

Results show that the dynamic calibration is frequency dependent and varies between individual transducers. Errors in excess of 15% can be introduced if static calibration factors are applied to dynamic measurement.

Transducers tested were Gaeltec type 4T, Bell and Howell 10 psi type 4-366, Tyco flush diaphragm, Kistler 7261, and Bruel and Kjaer 1/2" microphone.

2. THE DYNAMIC CALIBRATOR

Essentially this consists of a loud-speaker diaphragm D driven by an oscillator O with variable power and frequency. The loud-speaker casing forms one end of a long cylinder, the other end being an adjustable plane plunger with O-ring seal to the cylinder wall (Figure 1). The cavity length between loud speaker and plunger can thus be tuned to resonate at various frequencies.

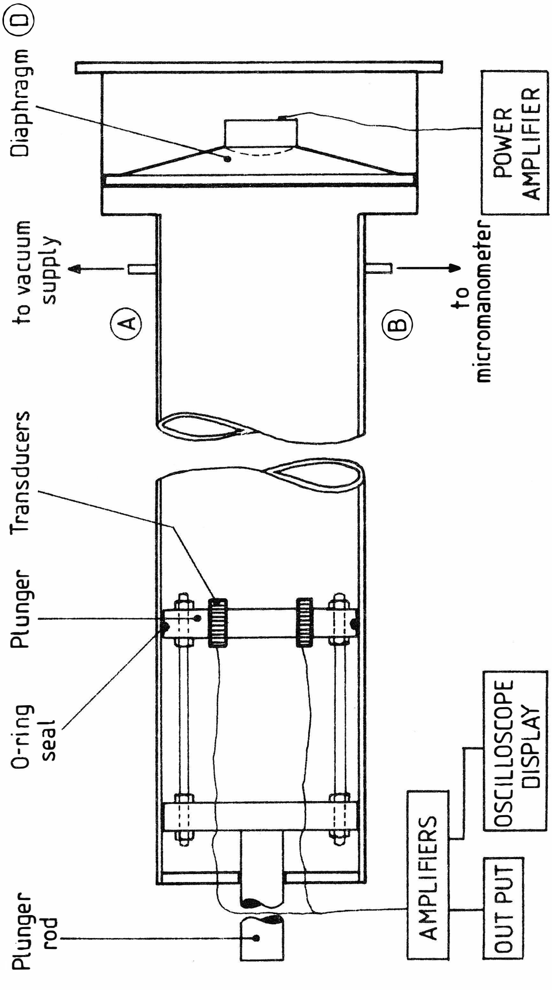

FIGURE 1 : Dynamic calibration rig

Transducers are mounted in the plunger with their sensors facing the loud-speaker and their static lines vented to the atmosphere. There are two connections to the cylinder, A and B; A is for a vacuum supply to control the mean pressure in the rig and B for a micro-manometer to measure this mean pressure.

With the components used in these tests fluctuating pressures of ± 50 mm water (r.m.s.) could be maintained up to 300 Hz, ± 25 mm water to 750 Hz and smaller values up to 1 kHz. Under resonant conditions the wave form was a good sine curve on the monitor oscilloscope. 70 Hz is the lowest resonant frequency with the existing cylinder and this was adequate for these tests. Lower frequencies could be investigated by moving the plunger close to the loud-speaker but this resulted in a very weak signal, of course.

Static calibration, too, may be undertaken in the rig by varying the vacuum supply pressure. Much lower pressures than the fluctuating test pressures are desirable to give an accurate static calibration and, typically, - 400 mm of water (static) was used for a test involving ± 50 mm water (fluctuating). Static calibration usually involves adjustment of a bridge network to a convenient value and in this case 2 mv per mm of water was used whenever possible.

3. TEST PROCEDURE

1. The required frequency and maximum output signal were selected on the oscillator.

2. The cavity was tuned to obtain optimum conditions, i.e. maximum

output signal strength and a good oscilloscope trace.

3. The oscillator output was reduced to give the required test pressure.

4. The oscillator was disconnected and zero and static calibration of the transducers checked.

5. The oscillator was re-connected and the r.m.s. output recorded.

6. Zero and static calibration were re-checked.

The bridge balance and gain were monitored frequently, because of the inevitable temperature sensitivity of low pressure transducers.

The results are generally presented as curves of r vs. f where r is the r.m.s. pressure ratio between the test transducer and the reference transducer and f is the signal frequency. The reference transducer was either the Bell and Howell flush transducer or the Bruel and Kjaer microphone.

4. TEST RESULTS

4.1 Consistency Between Gaeltec Transducers

The 21 miniature transducers were run in two batches because of space limitation and it was assumed that the true r.m.s. pressure at any particular frequency was the mean of the 21 recorded values.

On this basis Table 1 was compiled and it is noticeable that

(a) large variations occur;

(b) certain transducers (e.g. no.16) always read high, others (e.g. no.14) are always low;

(c) within reasonable limits the variation with frequency of a particular transducer from the accepted mean is not frequency dependent.

4.2 Use of Bell and Howell 4-366 as Reference

These transducers are used commercially, are very robust and have a good specification including a mechanical natural frequency "above 10 kHz". Their disadvantage is that the pressure range is 10 times higher than the Gaeltec's so that a large amplifier gain is necessary. However the instrument noise is still low but the zero shift is rather troublesome.

The protective inlet passages upstream of the diaphragm seem more suited to static than to dynamic pressures and since two of these transducers were available it was decided to convert one to a flush diaphragm transducer by machining off the inlet. A comparative test was then made, in the test rig, of the modified and original transducers and the results, shown in Figure 2, indicate that the standard inlet geometry is unacceptable for dynamic pressures. In this case r is the ratio between the original form and the flush diaphragm, modified, version. The flush mounted version was therefore used as reference.

TABLE 1 Gaeltec Transducers. Variation from the mean

Frequency (Hz)	% variation from mean																				
	Transducer Number																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
90	0	-2	-1	-4	-4	+5	-3	+6	+6	+5	-8	-3	-5	-3	-2	+5	+3	+4	+4	+3	-8
100	+1	-2	-1	-3	-3	+6	-2	+6	+6	+6	-7	-3	-5	-2	-2	+6	+3	+4	+5	+4	-7
200	-4	-3	+1	-2	-3	+1	0	+4	+3	+2	-2	-2	-2	-2	-8	+1	+6	+3	+3	+5	-2
300	-7	+2	+1	0	0	0	0	+3	+1	0	-3	-3	-2	-10	+3	+7	0	+2	+3	+3	-2
400	-8	+1	+5	+1	-1	+1	+1	0	-1	-2	+1	-1	+2	-10	+6	+9	0	+4	+6	+4	-2
500	-8	+2	+5	+2	0	+2	+1	+2	-1	-1	-2	-4	-1	-12	+3	+6	-2	+2	+3	+2	-3
600	-8	-1	+3	-1	-1	-1	-2	-1	-1	-3	-6	-7	-5	-15	+2	+5	-5	-1	+1	-1	-5
700	-7	+3	+9	+5	+4	+4	+3	0	+3	+2	-4	-5	-4	-13	+3	+6	-4	0	+2	0	-2
800	-5	+2	+8	-1	+3	+3	+3	+3	+3	0	-5	-7	-4	-4	+1	+6	-5	-2	-1	-2	-4

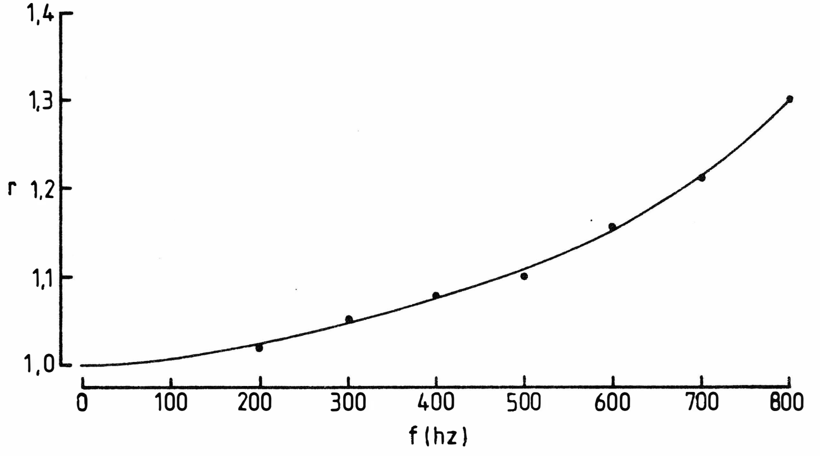

FIGURE 2 : Bell and Howell transducers. Effect of inlet passages

4.3 Gaeltec Referred to Bell and Howell

Test 1 was repeated to compare the mean Gaeltec performance with the Bell and Howell and the results are shown in Figure 3. It was established that these results were independent of signal level.

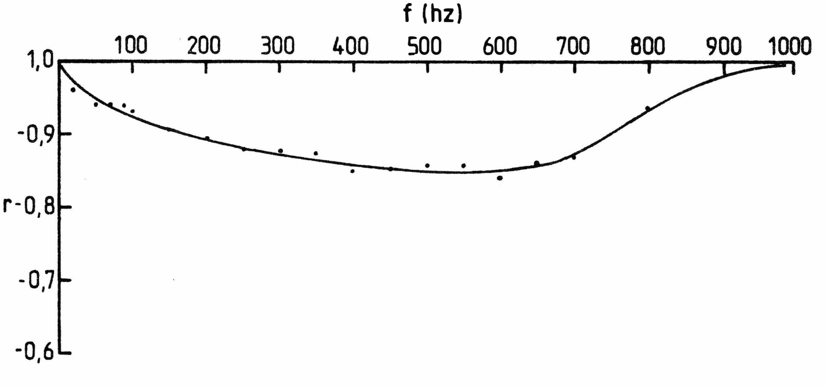

FIGURE 3 : Mean Gaeltec compared with Bell and Howell

4.4 The Tyco Open Diaphragm Transducer

This is similar in appearance and size to the Bell and Howell transducer except that it is produced as a flush-diaphragm gauge. It is intended for geotechnical work with a pressure range from 0 to 700 kPa and quasi-static loading and was marketed by Pro-lab of Melbourne. It is not of great interest in the present study but does show quite good agreement with the Bell and Howell up to 500 Hz. Both zero and gain were very unstable but, again, a very high amplifier setting was needed for the small pressures encountered. The results are shown in Figure 4.

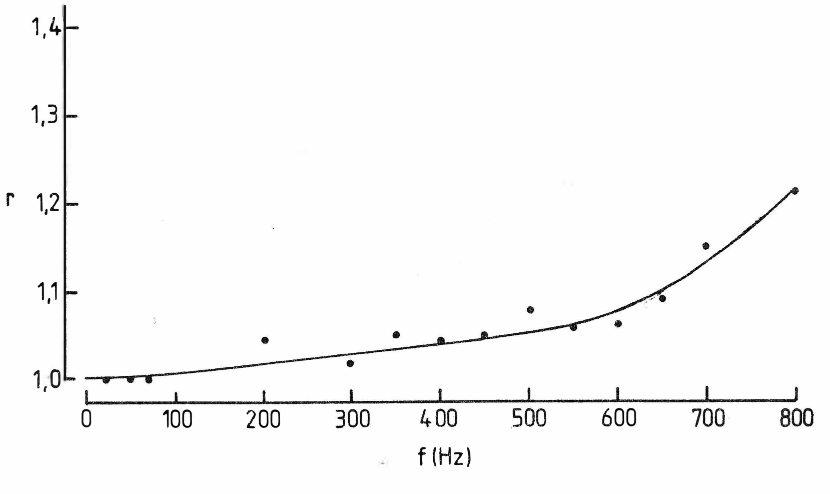

FIGURE 4 : Tyco compared with flush-diaphragm Bell and Howell

4.5 The B and K Condenser Microphone System

This is manufactured to comply with the American specification for laboratory standards ANSI S1.12-1967. Each cartridge has its own calibration and frequency response characteristic with a stability of 1 db over a very long time period. The frequency response curves are absolutely flat over the range involved in these tests.

The microphone requires a pre-amplifier to convert its charge to a voltage output and this involves a gain factor K and a frequency dependence at very low frequencies. The factor K is quoted for each pre-amplifier type and again has remarkable stability.

The system tested was a 1/2" cartridge type 4134 with pre-amplifier type 2615 supplied by Mechanical Engineering Department Laboratory. The manufacturers calibration was 12.25 mm water/volt. (120.17 Pa/volt).

This system was used to re-check the Gaeltec transducers generally as in 3 above. However, it had become clear by this stage that there was considerable variation in the dynamic calibration of the 21 transducers and the best ten were selected (i.e. those transducers that differed least from the overall mean) as "standard Gaeltec". The r-f curve for these is Figure 5 and this shows clearly the pre-amplifier frequency dependence at low frequencies. It also indicates that the manufacturer's calibration of the microphone system is some 6% high since r must be 1 at f = 0. Hence it was decided to use a calibration figure of 12.99 mm water/volt (127.43 Pa/v). On this basis Figure 5 has been redrawn as Figure 6 which also shows the Bell and Howell results of Figure 2 again. The close agreement of these two curves confirms the use of the flush-mounted Bell and Howell as a standard, at least up to 700 Hz and justifies the modified calibration of the microphone system.

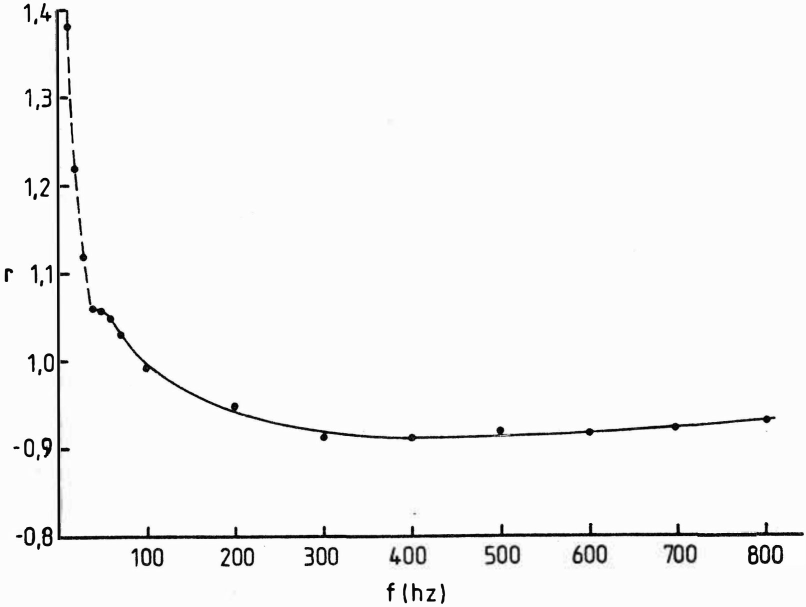

FIGURE 5 : Standard Gaeltec compared with B and K microphone (maker's calibration)

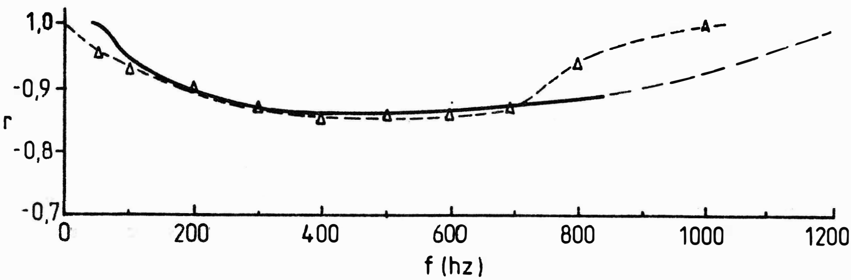

FIGURE 6 : Standard Gaeltec compared with B and K microphone (revised calibration) and with B and H flush diaphragm transducer

4.6 The Kistler Type 7261

This is a low pressure quartz transducer and may be mounted as a flush diaphragm sensor or with a protective cover. In these two forms it has specified resonant frequencies of 13 and 2.5 kHz respectively. The diaphragm is of large diameter (35 mm) and a charge amplifier is required to convert the electrostatic charge signal of the transducer into a proportional output voltage, with amplification. Unfortunately, it is not possible to calibrate the system statically but it is very stable, relying on the piezo-electric effect, and the manufacturer supplies calibration formulae for various conditions. A quasi-static calibration can be achieved by applying a step change of pressure which is retained for some 2/3 seconds and this was found to agree with the manufacturer's figure.

The transducer was used with the protective cover removed, preliminary tests having shown that the restriction affects its response above 300 Hz. In view of the specification and reputation of this transducer it had been hoped to establish it as a sub-standard and a number of Gaeltec transducers was run against it. The comparison was unsatisfactory involving large random errors which must be blamed on the Kistler transducer in view of the consistency of previous tests. Subsequent tests of this transducer against the B and K microphone gave similar unsatisfactory results.

However it was established that the "r factor" was independent of signal strength and varied 20% with frequency in the range 0 - 1000 Hz but it also varied with the distance between transducer and signal source. It is suggested that the Kistler transducer is susceptible to mechanical vibration in addition to the pressure signals, as installed in this test rig, and it is therefore unsatisfactory.

Figure 7 shows the widely scattered results obtained.

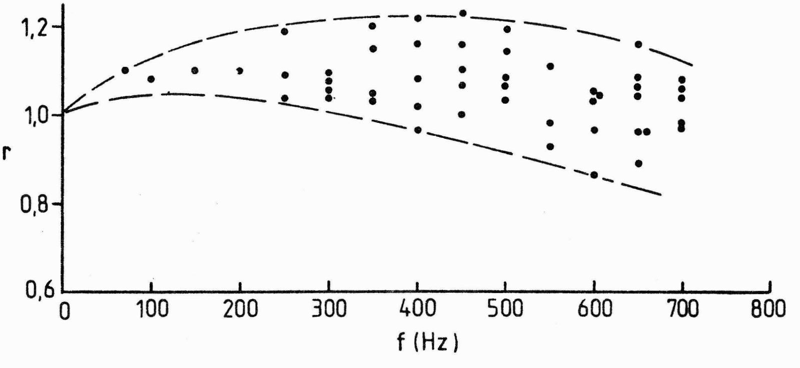

FIGURE 7 : Kistler compared with Bell and Howell microphone

5. CONCLUSIONS

5.1 The B and K microphone is the best laboratory sub-standard for transducers but the calibration constants require periodic checks.

5.2 The Bell and Howell transducer, with the inlet passage machined away is very satisfactory up to 700 Hz.

5.3 The Kistler 7261 transducer is unsuitable in this application by virtue of its response to mechanical vibration.

5.4 Gaeltec transducers require the following corrections to their static calibration when used to measure dynamic pressures:-

(a) The r factors shown in Figure 8 must be taken into account for "standard Gaeltec" transducers and vary with frequency. A "standard Gaeltec" transducer, in this context, means one whose dynamic behaviour does not vary from the mean by more than 2 percent, i.e. Nos. 4, 6, 8, 9, 10, 16, 17, 18, 19, 20.

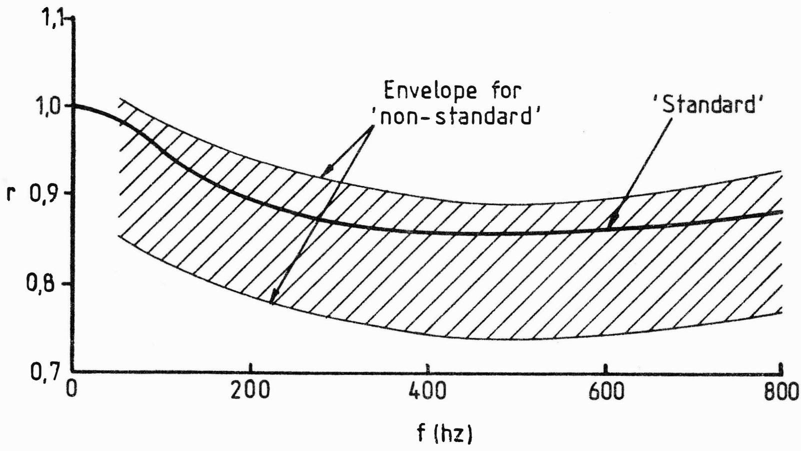

FIGURE 8 : Variations between individual Gaeltec transducers

(b) "Non-standard" Gaeltec transducers require additional corrections as shown in Figure 9, which compares these transducers with the standard Gaeltic. The data are listed in Table 2.

5.5 Table 3 lists the manufacturers' references for the 21 Gaeltec transducers investigated.

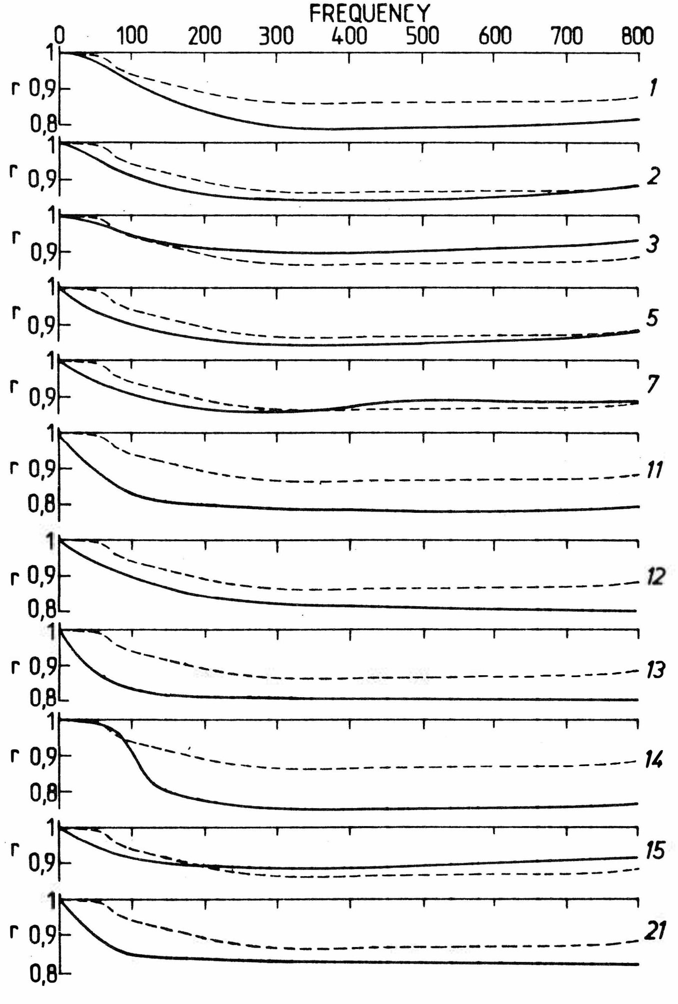

FIGURE 9 : Dynamic calibration factors of the Gaeltec transducers

TABLE 2 r Factors for Gaeltec Transducers

Frequency	r Factors for Gaeltec Transducers																				
	Transducer Number																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
70	.97	.94	.97	.95	.91	1.03	.93	1.01	1.02	.99	.88	.92	.85	.98	.93	1.00	1.01	1.05	1.00	1.01	.86
100	.91	.91	.93	.91	.90	.96	.91	.98	.98	.93	.79	.89	.84	.91	.91	.94	.97	.98	.96	.97	.82
200	.84	.87	.91	.89	.87	.91	.88	.92	.91	.88	.80	.84	.82	.78	.90	.91	.93	.93	.93	.93	.84
300	.79	.84	.90	.88	.85	.87	.86	.87	.87	.83	.80	.83	.80	.76	.88	.90	.86	.89	.88	.89	.83
400	.78	.85	.90	.86	.86	.87	.87	.86	.84	.80	.79	.81	.79	.75	.88	.89	.87	.86	.88	.88	.83
500	.80	.86	.92	.83	.87	.87	.89	.86	.86	.81	.80	.84	.82	.76	.90	.90	.84	.88	.88	.88	.83
600	.80	.85	.91	.91	.86	.88	.88	.86	.86	.81	.77	.80	.80	.74	.90	.91	.84	.88	.88	.88	.81
700	.80	.86	.93	.88	.86	.88	.88	.86	.86	.82	.79	.82	.82	.77	.91	.91	.86	.88	.88	.88	.82
800	.82	.88	.91	.91	.88	.88	.88	.88	.85	.85	.79	.79	.79	.77	.91	.91	.85	.88	.88	.88	.82

TABLE 3 Transducer serial numbers

Transducer	Manufacturer's Designation
1	8388
2	6163
3	7276
4	A296
5	A298
6	8340
7	7278
8	8336
9	8329
10	8341
11	7277
12	6168
13	6165
14	B465
15	A297
16	B464
17	8332
18	8339
19	8337
20	8333
21	6162

APPENDIX A - NOTATION

Symbol	Meaning
f	frequency
r	rms pressure ratio test transducer/reference transducer

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