# ELECTROSTATIC ACTUATORS – A Role in Calibration

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## 1. INTRODUCTION

It is accepted internationally that acoustical measurement instrumentation used for standardised measurement methods (e.g. BS 4142, ISO 9614) should be periodically verified. The UK currently has six laboratories accredited by the United Kingdom Accreditation Service (UKAS) for acoustical calibrations, four providing verification services for sound level meters, with many hundreds of tests being undertaken annually. Such verification testing is usually based on British Standard BS 7580[1], which gives a subset of tests from the main international specification standards IEC 60651[2] and IEC 60804[3]. The tests within BS 7580[1] are split into two parts: the signal processing features of the meter are tested using an electrical signal substituted for the microphone and then, with the microphone in place, acoustical tests are performed. Use of an electrostatic actuator for some of these tests, particularly for measuring the overall frequency response, is now common. However, it is only recently that preparations have begun to standardise electrostatic actuators for determination of frequency response. A new standard, IEC 61094-6[4] has been under development for some time and is now at the final draft stage for committee voting. Given the extent of verification testing carried out in the UK, it was considered important to examine that the test methods proposed within the draft standard are reasonable and can be practically applied, and that measurement requirements and criteria can be realised. Experimental work has been conducted at NPL to determine the effect of using different models of actuators on the same microphones. The influence of background noise in the laboratory has also been investigated and a range of actuator drive signals compared. This paper presents some of the results obtained to date.

## 2. STANDARDISING THE USE OF ELECTROSTATIC ACTUATORS

It is well recognised that electrostatic actuators offer an efficient and relatively low cost method of determining the frequency response of a microphone or acoustical measurement system. The devices are commonly used in secondary calibration laboratories as part of the verification tests conducted on sound level meters (SLM's). Up until recently the use of actuators has been based on available theory, with no reference to specification standards on design and construction of the devices, or on method of application. This being the case, there is limited evidence to indicate the reliability of the method with respect to other commonly adopted methods such as pressure reciprocity.

The well established theory can be explained in relatively basic terms. The electrostatic actuator is essentially a rigid and electrically conductive plate, which is placed in parallel to the microphone diaphragm. This configuration then forms an electrical capacitor, such that when a voltage is applied between the parallel plates, the actuator generates a force F (see Eqn 1)[4] and an electrostatically produced pressure excites the microphone diaphragm. Use of the device is limited to condenser type microphones where the outer surface of the microphone must also be electrically conductive.

$$F = -\frac{\varepsilon_{gas} S_{act}}{2d^2} U^2 \qquad (1)$$

where $\varepsilon_{gas}$ = dielectric constant of gas in the space between actuator and microphone, (F/m)
$S_{act}$ = effective surface area of the actuator above the active diaphragm area ($m^2$)
$d$ = effective distance between the actuator and diaphragm (m)
$U$ = voltage applied between the actuator and microphone diaphragm, (V)

### 2.1 THE DRAFT STANDARD: IEC61094 – PART 6

The above theory is commonly in use, with different devices and bespoke calibration systems employed in commercial calibration services, but unlike other calibration measurement methods, there are no standards for reference. As such, IEC/TC29/WG5 proposed the development of IEC61094 - Part 6: "Electrostatic actuators for the determination of frequency response" [4], which forms part of a series of specification standards dealing with measurement microphones.

In developing Part 6, it was considered important to work towards a standardised design for the device with a validation procedure to ensure adequate performance when applied in practice. The scope of the draft standard in its current format suggests that the information provided is wide ranging, stating that it gives guidelines on design of electrostatic actuators, methods for validation of the devices, and provides techniques on applications of the devices. The development of IEC 61094–6[4] has now reached a final committee draft stage.

## 3. CONCERNS

A general concern about using electrostatic actuators for calibration is the question of how confident the user can be in obtaining the same answer when using different actuators to verify the frequency response of a microphone or measurement system.

### 3.1 SPECIFIC CONCERNS ARISING FROM THE DRAFT STANDARD

In examining the draft standard[4] it is important to question whether the information provided is useful and that the specifications are reasonable for the user, providing sufficient technical detail in a well constructed and easy to interpret manner. During the development of the standard there were a number of issues, which caused some concern for the UK. For example, the standard stated that in practice, the tests, which are performed to validate that an actuator will fulfil the requirements of design criteria, could be conducted with one type of microphone, which is selected to represent other types of microphone with similar design. This approach though apparently helpful in reducing effort for the user, was considered questionable. What would the result be for different combinations of microphone and actuator, and what degree of confidence would result if an actuator was tested for performance only with one model of microphone?

A global concern arising from the content of the draft standard was the lack of information provided on measurement uncertainty associated with the use of electrostatic actuators. Previous work on the electrostatic actuator method for microphone calibration [5] noted that the uncertainty of determining absolute pressure is high compared with other calibration methods. One particular study [6] noted a range of potential uncertainties associated with actuator response calibration, including random uncertainties caused by acoustic noise and systematic uncertainties caused by differences in mechanical dimensions. IEC 61094-6[4] acknowledges that relatively large uncertainty is associated with the separating distance, stating that microphone sensitivity cannot be determined with reliability. Following a review of the draft of this standard the UK suggested that it be expanded to provided uncertainty details for the determination of the electrostatic actuator response as well as guidance on how the uncertainty from such measurements propagate into other applications for actuators.

## RESEARCH TO SUPPORT DEVELOPMENT

"Electrostatic actuators are efficient, accurate, and reliable for microphone response calibration"

**…ARE YOU SURE?**

It has already been explained that there is a general concern that there may be differences between actuators, as well as a number of specific concerns arising from the current proposals for standardising the use of electrostatic actuators.

So what has NPL been doing in relation to these concerns and to support the development of a standardised method? There has been minimal direct involvement in the development of the standard other than technical and editorial review of each draft with contributions made at meetings of IEC/TC29/WG5. NPL's participation has been to check the substance of the proposed standard on behalf of UK industry, recognising that there is a need to ensure that the specifications are correct, appropriately set at a level that users can apply the methods and produce reliable results, at a reasonable cost. Under the National Measurement System (NMS) operated by the Department of Trade and Industry (DTI), NPL embarked on experimental research to investigate the use of electrostatic actuators for the acoustical verification of sound level meters and particularly to ensure that the proposed tests methods are reasonable and can be practically applied, and that the requirements quoted within the standard can be realised. It was also a good opportunity to confirm, or otherwise, the place of the electrostatic actuator method along side other methods of calibration.

The following section sets out details of the experimental investigation, with discussion of the results obtained from a series of frequency response measurements made on common working standard (WS) free field microphones using electrostatic actuators.

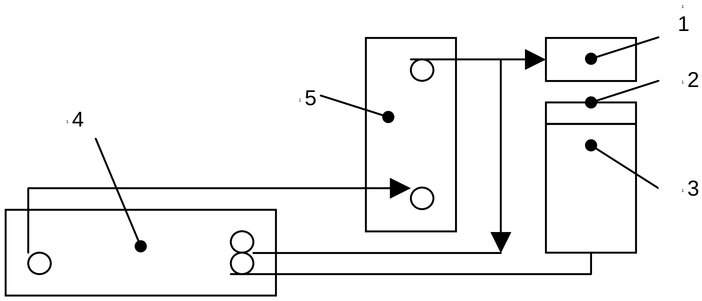
# 5. THE INVESTIGATION

The project set out to gain more knowledge on the performance of electrostatic actuators. In particular, the aim was to determine the effect of using different actuators on the same microphones.

## 5.1 EXPERIMENTAL SET-UP

The experiment was set up in accordance with specifications given in IEC 61094-6[4]. Figure 1 illustrates schematically the instrumentation set-up.

**Figure 1 Instrumentation set-up**



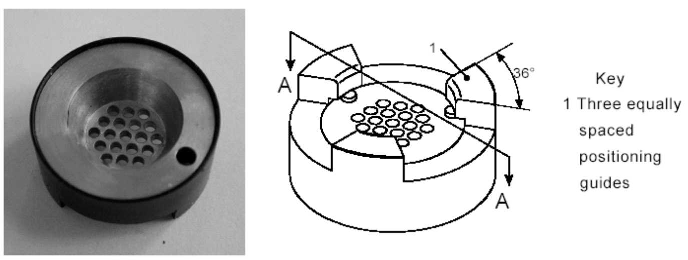

1 Actuator
2 Microphone
3 Preamplifier
4 Combined signal generator and measurement instrument
5 Actuator drive amplifier

To examine the performance of the electrostatic actuator method for microphone response calibration, a measurement plan was devised around the validation recommendations given in IEC 61094-6[4]. Essentially, a range of microphone and actuator combinations was tested, enabling determination of repeatability values, and analysis of the uniformity of various devices. Also, during the process of setting up the experiments, it was found that additional issues needed investigation. Anonymous descriptions have been given at this stage for commercial confidentiality reasons.

### 5.1.1 Electrostatic actuators

Three sets of three actuator models were acquired for the project. Two of the sets were made up of a commonly used design of electrostatic actuator for WS2 microphones as shown below.

**Figure 2. Common actuator design for WS2 microphones** (Ref [4])




The third set employed a different design principle, forming an integral part of a microphone protection grid. These were used only for the “right to the rim” design of microphone.

### 5.1.2 Microphones

Free-field microphones were selected for the experiment as it was considered that these are the most common type of microphone to be calibrated by the electrostatic actuator method at accredited laboratories. Five different models were acquired for the project. Additionally, multiples of three microphones of the same model were obtained for three of the different models.

### 5.1.3 Reference measurements

In addition to the experimental measurements made using the actuators, the reference sensitivity was determined using a calibrated pistonphone before and after each set of actuator measurements. Records of temperature, and atmospheric pressure were also taken in the laboratory.

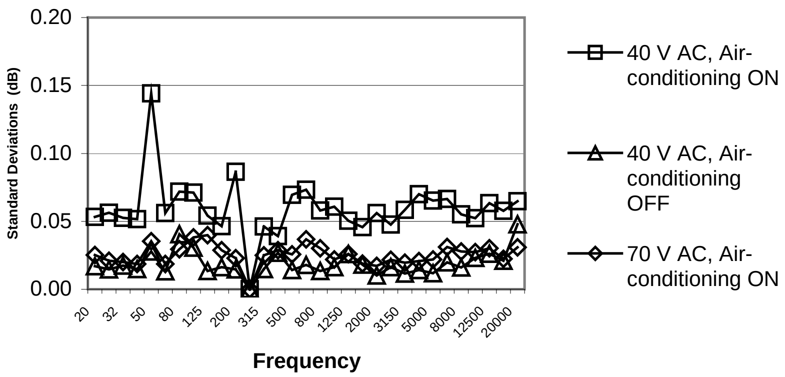
### 5.1.4 Background Noise

In setting up the experiment it was revealed at an early stage that background noise needed to be considered. The draft standard[4] recognises the influence of the surrounding environment, but no practical guidance is given, only mentioning that particular care should be taken if the surrounding environment introduces high peaks in the resulting response.

Adopting the configuration recommendations of the draft standard, the actuator signal should be set up such that the applied DC voltage should be at least 20 times larger than the AC voltage. Furthermore, the standard states that for a nominal distance of about 0.5 mm between the actuator and diaphragm, the DC voltage applied to the actuator is typically about 800 V. This would therefore require that the AC voltage does not exceed 40 V.

However, initial measurements indicated that in order to counteract the effects of background noise, a lower voltage ratio may be needed. It was found that the effects of background noise, primarily due the air-conditioning units, were noticed in the measurement results when the 800 V DC, 40 V AC settings were selected. The effect was most apparent a low frequencies, as indicated in Figure 3 below.

**Figure 3. Influence of background noise on repeatability**




It can be seen that with the air-conditioning on, and the recommended settings applied, spikes appear at low frequency, most dominant at around 50 Hz, and 200 Hz. The influence clearly degraded the measurement repeatability.

It was possible to control background noise in the laboratory by switching off the air-conditioning. The results obtained under these conditions show a much better repeatability, with the prominent spikes at low frequency removed. As an alternative to switching off the air-conditioning the effect of increasing the drive signal was tested. Voltage signals were changed to 800 V DC with 70 V AC. It can be seen that the repeatability at low frequency improves in a similar way to the effect achieved by turning off the noise source.

## 5.2 REPEATABILITY

The repeatability for three different models of actuator on a range of different free-field microphones commonly used on Type 1 SLM's was examined.

### 5.2.1 Repeatability performance of actuators

Measurements of frequency response were replicated ten times with the recommended settings. The actuator was removed and fully replaced onto the microphone between individual measurements. The results were then normalised at 250 Hz and the experimental standard deviation calculated. IEC 61094-6[4] specifies that the standard deviation shall not exceed 0.05 dB.

Figure 4 indicates that this criterion is generally achieved at most frequencies for some of the actuator and microphone combinations. However, microphones B and D were found to fail the criterion at some frequencies. All results indicate spikes at 50 Hz and 100 Hz, which are likely to be inherent with the measurement system rather than the actuator, so repeatability may be improved at low frequencies. However standard deviations at high frequency were found to be higher, with microphones B and D just exceeding the 0.05 dB criterion. Where such cases found it may be necessary to state the frequency limitations of the actuator and microphone combination. During the measurement procedures, where the actuator was removed and replaced back onto the microphone, it was noticed that the fit of the actuators was not the same for all microphones. In particular, it was noticed that in coupling actuators to microphones B and D, the fit was less rigid than other microphones. In the draft standard[4], it is noted that the separating distance between the coupled microphone and actuator can have a significant effect. This is demonstrated if we consider the variation in the separating distance d, between the actuator and microphone using equation 2. The effect of varying the distance between the actuator and diaphragm by 0.01 mm will be to generate a difference in absolute measured level of 0.35 dB. However after normalising, most of this difference should be removed, except perhaps at higher frequencies where some difference may remain due to the the differing loading effect of the actuator.

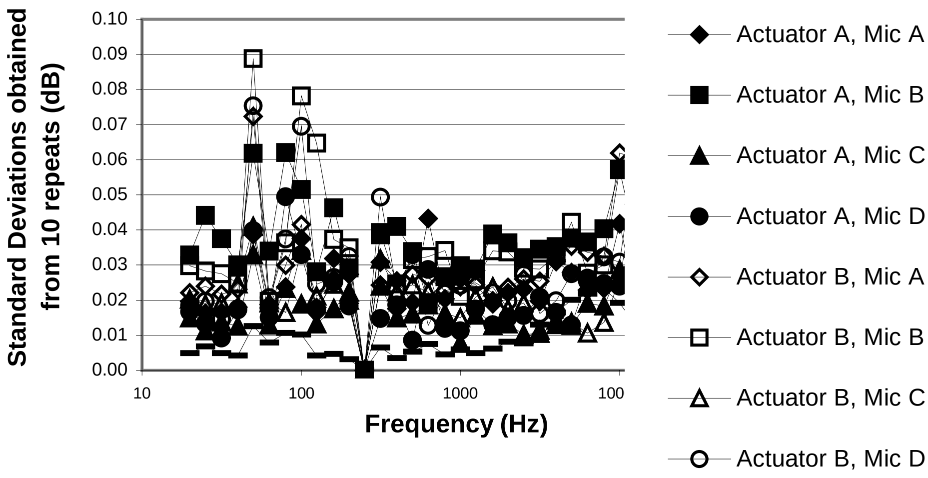
$$p = \left[\frac{\varepsilon_{gas}\, a}{d^2}\right] U_0\, u \qquad (2)$$

Where $a$ = ratio between effective actuator area and active diaphragm area ($m^2$)
$U_0$ = DC voltage applied between actuator and microphone diaphragm (V)
$u$ = rms value of the AC voltage applied between actuator and microphone diaphragm (V)

It was also observed that the absolute measured level for microphones B and D was lower than that for microphones A and C.

Actuator C, which has a fixed position design, whereby it is integrated with the microphone protection grid, was found to have the best repeatability.

**Figure 4. Repeatability for a range of Actuator & Microphone combinations**

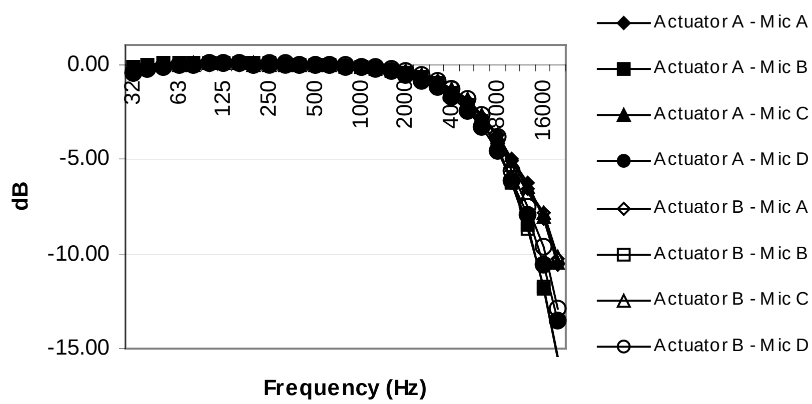



## 5.3 UNIFORMITY OF ACTUATORS

To specifically examine the differences between different actuators, measurements of frequency response were again conducted. Replicated measurement results were normalised at 250 Hz, and the mean response calculated. These data were used to determined differences between models of actuator, the results of which are discussed in section 5.3.1. IEC 61094-6[4] specifies a procedure for validating the uniformity of actuators of a given model, requiring measurements to be made with 3 actuators of the same model. It stipulates that the average responses shall not at any frequency deviate by more than 0.05 dB from the average of all measurements. Validations were made for the actuators using a range of microphones and the results are discussed in section 5.3.2.

Generally actuator responses are relatively close for much of the frequency spectrum, as illustrated in Figure 6, which shows the mean responses determined for a number of free field microphones with different actuators. It is apparent that deviations occur at very low frequency and at high frequency above 5 kHz.

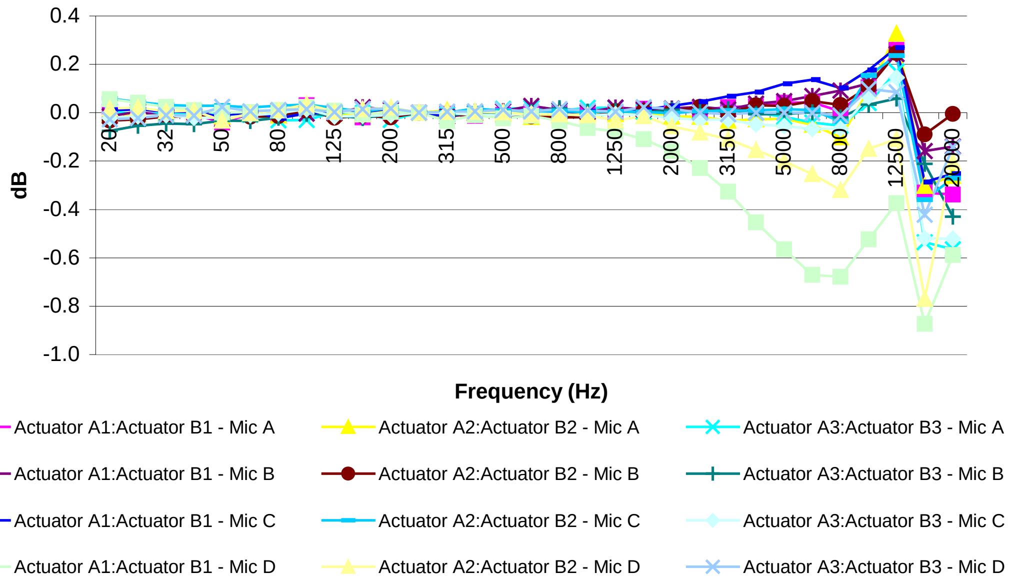
**Figure 6. Measured actuator responses for a range of microphones**




### 5.3.1 Differences between different models

Figure 6 demonstrates different actuator responses obtained for different microphones. Analysis was conducted to examine the differences between different models of actuator. Figure 7 shows the differences between frequency responses measured on the same microphones with two different models of actuators.

**Figure 7. Differences between models of actuator**




It can be seen that significant differences between models were determined at high frequency, the trend holding for all the microphones tested. This supports the comments made in [6] that mechanical resonance in the combination of actuator, microphone, preamplifier housing and holder for the preamplifier can contribute to measurement uncertainty at frequencies above 5 kHz.

### 5.3.2 Differences between same models

The validation procedure as specified in IEC 61094-6 was followed enabling evaluation of the uniformity of actuators of a given model. Three actuators of the same model were compared and it was found that differences in response were in general found to be smaller than those between different models of actuator. The results varied according to the microphone used for the tests. Where the same make of actuator and microphone was used, the stipulated uniformity criterion of 0.05 dB was generally met, but with other microphones there was a tendency for failure at high frequency.

## 5.4 TECHNICAL COMMENTS ON IEC 61094-6

Earlier in section 3.1, it was noted that there were some initial concerns about the IEC 61094-6[4]. The investigation has led to a number of conclusions in relation to the specifications given in the standard.

Our measurements have shown that background noise can be a major influence on the measurements, even under relatively well-controlled laboratory environments, when the recommended test levels in the standard are applied. Information on the influence of background noise is difficult to specify since it depends on the microphone under test and other conditions of the measurement. The need has therefore been highlighted to pay particular attention to this aspect when implementing measurements with electrostatic actuators, particularly when investigating measurement repeatability .

Most microphone and actuators combinations pass the 0.05 dB criterion. However not all did, particularly at high frequency, which highlights the fact that it is not possible to validate an actuator model in isolation to the microphones it is meant to be used with. The standard needs to make clear that the combination of actuator and microphone is the subject of the test procedure.

There are differences between measured mean responses obtained with difference actuators, which again highlights that there may be differences between different combinations of microphone and actuators. If an actuator is tested with one selected microphone and found to pass the criteria but is then used on a range of other microphones of similar design, errors may occur, and would require corrections to be applied. It is therefore suggested that the standard refers to actuators with model-specific microphones if this is not already the intention.

The investigation highlights problems of measurement uncertainty. It has been recommended that information on uncertainty of measurement be included where appropriate within the text of the document, and to provide additional information in an Annex. It was acknowledged that the Annex might only offer in a descriptive format, the potential uncertainties arising from measurements using an electrostatic actuator. However, this would be more useful for the user, than no information at all. Further work may be needed to obtain quantitative data.

## 6. CONCLUDING REMARKS

It is accepted that the use of electrostatic actuators has a role in the calibration of measurement microphones, offering speed and efficiency leading to low costs for industry. However, it is equally important that the application of the devices deliver accurate and reliable measurement results. In standardising the application of actuators for determination of frequency response, investigations have ascertained that there are a number of technical issues to be addressed.

Attention has been raised with regard the need to consider carefully, background noise sources influencing measurements in the laboratory. It has demonstrated some of the shortfalls of the validation procedure included in IEC 61094-6[4]. It has highlighted the need to consider measurement uncertainty when using electrostatic actuators.

## ACKNOWLEDGEMENTS

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