ERNTEC
ELECTRONICS TECHNOLOGIES

WE THINK
OUTSIDE
THE BOX.

Noise in Microdrive Applications

Introduction

With the rise of automation and the growing pervasiveness of electronic control, small DC motors have become an increasingly common component for systems in all manner of applications. The sound & vibrations generated by a system can be an important factor in the overall performance and suitability of the system within a given application. For example, a ventilator device where the user's experience might be negatively affected by excessive noise.

This whitepaper aims to discuss basic concepts of noise, identify some common sources of sound & vibration in small DC motors and then suggest some things to consider when designing a system that uses small DC motors. It is aimed at designers of systems that use small DC motors and their end users.

For the purposes of this white paper, we define a small motor as those brushed, brushless and stepper devices with a diameter less than 80mm. There are other technologies such as linear drives and piezo motors for which similar principals can be applied but they should be treated separately. We shall also use the terms small DC motor, drive, or "Microdrive" interchangeably.

What is Noise?

Technically, the term noise can be broadly defined as an unwanted signal made by variations in a propagating system. Sound and vibrations travel through solids and liquids as pressure waves and into the human ear where our brain decides how it is perceived.

To demonstrate how acoustic noise travels through a mechanical system consider the common experience of driving in a car. Here there are many sources of sound propagated to the driver via two main transmission paths as shown below in Figure 2 below.

The sounds of the engine or from interaction with the road and the wind on the chassis are transmitted through the air. Since the car engine is also an oscillating element, it transmits vibrations through the vehicle body that the driver can feel through the seat and floor. This is also true of other elements interacting with the system such as the road and even the wind.

This demonstrates how acoustic noise can be categorised as either "Structure borne" or "Air borne". How "noisy" an observer perceives all this to be is subjective. It is important to note that the way a vibration is transmitted throughout the entire system can drastically change the overall acoustic quality of the sound heard by an observer.

Therefore, to minimise undesirable sounds and vibration during design of a system that contains oscillating elements, it is best to consider possible transmission paths across as much of the full system as is practicable.

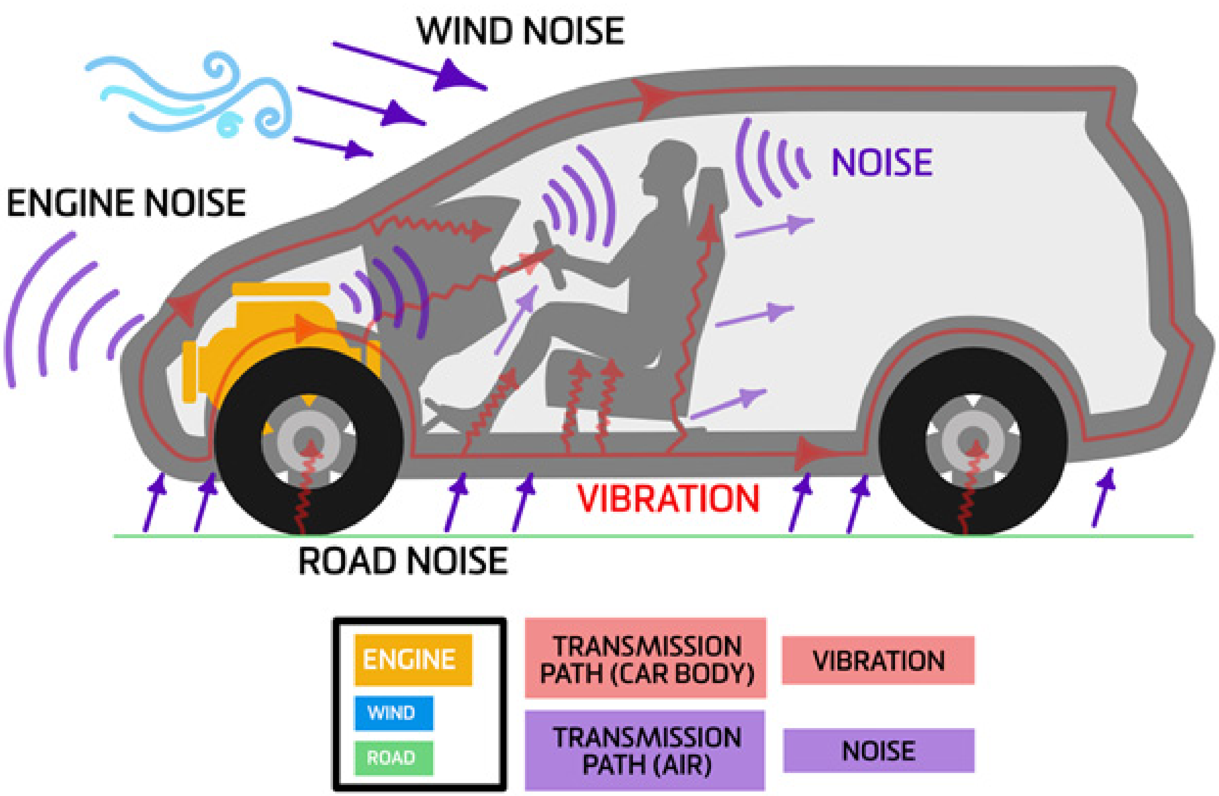


Figure 2. Transmission of noise & vibration

Noise Measurement and Perception

The common range of human hearing is between 20Hz to 2kHz. Sensitivity decreases at the low and high end of this range at a rate that varies from person to person (and decreases further as we get older). Sound quality can be perceived quite differently from person to person and there are many factors that might affect a person's perception of a sound. Auditory perception can be characterised by 3 properties:

1. Pitch (Frequency in Hz)
2. Loudness (Decibels in dB)
3. Physical sensation (Vibration).

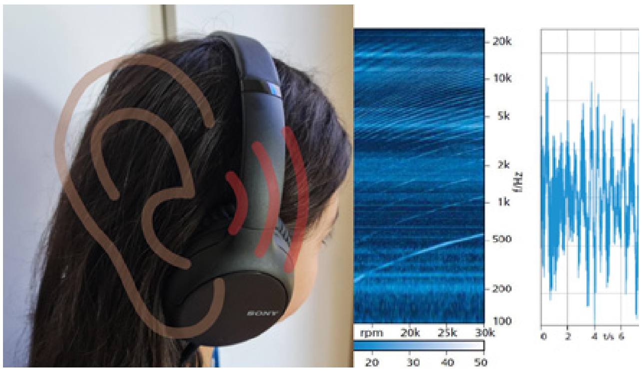
What a human hears or feels is defined not only by the source of the effect but also by how it is transmitted and lastly how it is perceived. In other words, the source of the sound/vibration must have a transmission path to the ears and to the touch sense. This is important because the transmission path itself can often be perceived as the source of the sound.

If noise mitigation is important then defining the acoustic system needs to be as objective as possible. In our car example the driver's experience is dependent on their sensitivity to vibration and certain sounds. Automotive engineers use Noise, Vibration & Harshness (NVH) standards to assess acoustic performance of a vehicle in design, manufacture, and testing. This is complex and costly but provides some objective measure of acoustic performance and sets a measurable quality. Automotive manufacturers implement this measure on a cost benefit basis because the consumer has a certain quality expectation.

Many of the NVH concepts could be applied to a DC motor system. Metrics such as echo, distortion, delay, and frequency response can all be measured objectively according to various standards. What might become subjective is the interpretation of results. Objective measurement of sound and noise in a multi-dimensional system requires clear definition, precise equipment, and complex analysis techniques (Examples are FEA (finite element analysis) for simulation and FFT Spectrum analysis for testing. When designing small DC motors, the manufacturer needs to consider which elements in the construction are critical in terms of noise versus motor performance.

Noise in DC Motors

All DC motors exhibit some level of sound/vibration and electrical variance. Manufacturers of small DC motors design for motive performance and control to meet the demands of a variety of use cases. Therefore, designing for very low noise is seen as a complex and expensive investment more suitable for custom implementation.



Most will incorporate measures that consider common sources of noise such as:

- Electrical Noise
- Unwanted Vibrations/Acoustic Noise

Electrical Noise

Electrical noise can cause interference with control and system electronics.

The two main types of electrical noise are:

- Power Line noise.
  Powerline noise can impair sensors and affect the voltage on your electronics powerline.
- Electromagnetic interference (EMI)
  Risks performance degradation of surrounding circuitry & motor drive electronics.

We will use the example of a DC motor with a brushed commutation as per Figure 1.

When the commutator switches current flow in the windings a "noise spark" occurs (between brushes and commutator).This occurs at the timing of the commutation and causes fluctuations in voltage than can be back fed to the power line and also emit EMI noise.

Electrical noise can be mitigated in many ways. Examples include adding filters and following EMC practices to ensure the operating environment is optimal for the application.

Unwanted Vibrations/Acoustic Noise

All DC motors vibrate, it is an intrinsic characteristic of kinetic energy being lost to the environment. A normally operating DC motor transmits low acoustic noise in air (less than 45dB). Often it is the way the motor is installed or mounted that will change or increase the loudness and/or pitch of the noise.

Although manufacturers attempt to minimise the amount of motor noise with quality and control measures it is important to note that once the motor is incorporated into a larger system, it cannot be considered in isolation. The motor is now a source of noise within a larger operating environment

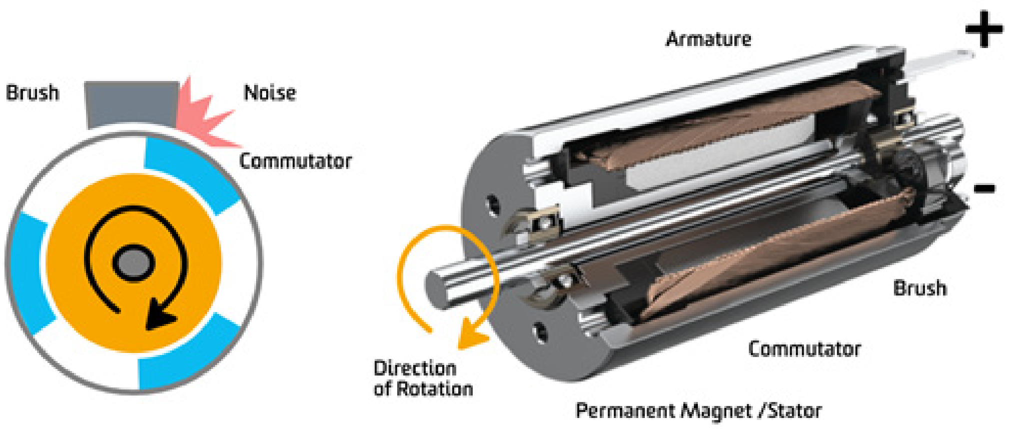


Figure 1. DC Motor commutation

and any elements attached the motor can become transmission paths.

In fact, any DC motor system can be viewed like the car analogy we discussed to show structure & air borne transmission of noise as shown in Figure 3.

- Structure borne vibrations will propagate to anything connected to the motor surfaces (housing, flange to mounts, gearheads, couplings etc.)
- Air borne noise between elements of the system interact with surroundings.

The typical source of vibration from the motor itself can be classified in two ways

- Electromagnetically induced
  o Vibrations caused by the excitation of electromagnetic forces in the motor.
- Mechanically induced
  o Any imbalances, misalignment, and friction forces between moving parts inside the commutation system cause vibration.

Electromagnetically induced

Common causes for electromagnetically induced vibration are:

- Excessive radial movements due to magnetic effect of current in parallel wires
- Power switching
- Feedback errors (or commutation noise)
- Residual holding torque.
- Excessive brush sparking at current collector rings or commutators.

Many of these effects are very hard to minimise and are accepted by manufactures as being the normal operating conditions of the motor.

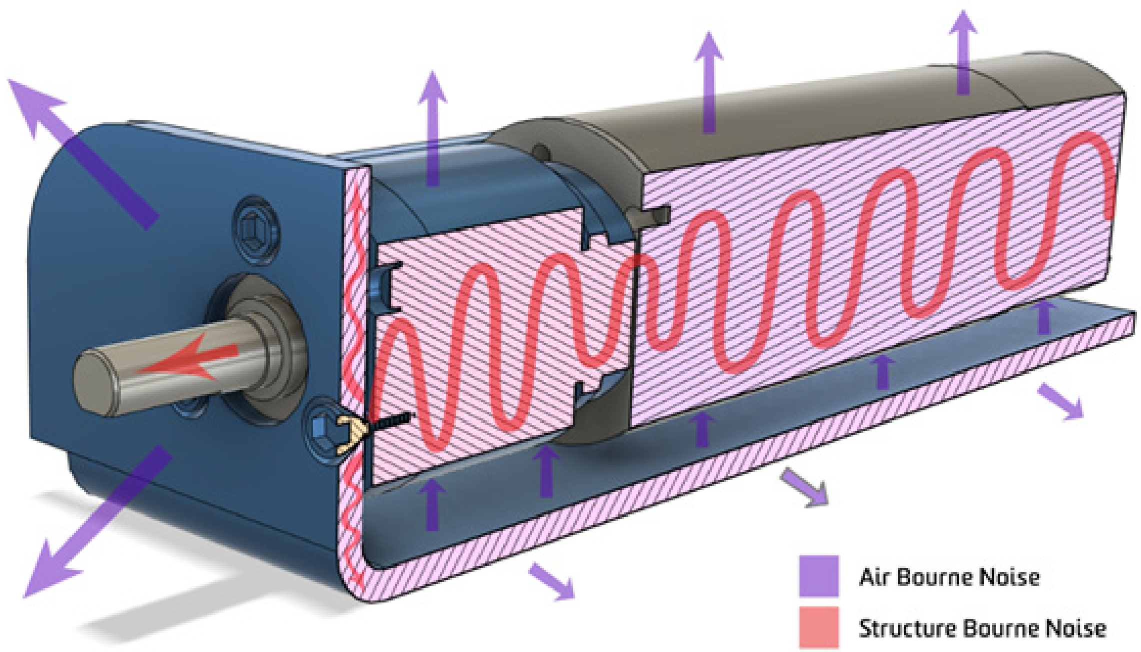
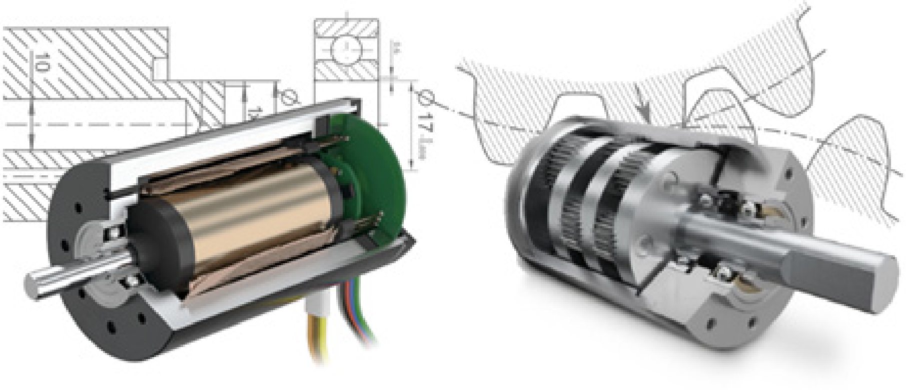


Figure 3. Noise resonance and vibrations propagated through structural and air transmission paths



Mechanically induced Vibrations

Even high-quality manufacturers must accept some level of variation in component tolerances and construction. Common sources for mechanically induced vibrations are:

- Loose or unbalanced Bearings:
  - Loose bearings cause vibration uneven movement and early wear on attached elements
  - Common causes are improper bearing lubrication and manufacture defect
- Imbalanced rotor:
  - A weighted spot can introduce centrifugal force about the axis
  - External imbalance can be introduced if attached elements (e.g., a fan blades) are not properly balanced (especially when speed increases)
- Misaligned gears and drive elements:
  - Gear teeth that lose contact or become broken and worn down, and grind on one another
  - Poor alignment of any drive elements such as a coupler or a pinion can cause rotational fluctuations

To minimise noise from these sources, manufacturers incorporate measures such as shaft balancing and high level of quality control for critical components like bearings, shafts, and gears.

Designing a Low Noise System

Although the levels of acoustic noise in a small DC motor operating "normally" are minimal the quality of the sound being transmitted throughout the system can be critical to the success of an application.
If an application requires low noise operation (for example a ventilator mask where user experience is important) it greatly helps to define what is normal or expected noise and what could be a potential issue.
Important questions to ask concerning noise are:

1. Why is noise a factor for this application?
   - Qualitative factor – Is the underlying issue how the noise is perceived (Then refer to item 4)
   - Quantitative factor – Does the noise need to meet an objective standard
2. What aspect of noise is most for important?
   - Are here are objective ways to measure sound quality required.
     Examples: Pitch, Loudness
   - Interpretation of the results of a measurement can be subjective depending on what is being sought.
3. What integration factors will affect noise quality?
   - Examples: Enclosure, Mounting type, Proximity to user
4. How will your design and manufacture control this aspect of the product?

The verification of noise has the potential to greatly increase time to market and cost. Therefore, collaborating with a motor manufacturer who can either design a custom solution or offer customised standard products can be a smart move.

Typical options for customisation are

- Extra level of rotor balancing
- Special Lubrication
- Change of bearing type
- Integrated electronics
- Drive element integration
- Noise reductive mount options
- Special binning of components
- Pre-Testing (For example. run in tests, no-load lifetime testing)

It all boils down to the understanding that one condition or a combination of elements can lead to motor vibrations — and it's not always easy to find the exact source. This is especially true since irregularities can arise from supplementary devices and not only stem from the equipment itself.

Reduce Noise Outside the Motor

If possible, it's always best to reduce noise directly at the source point. You can also look at ways to interrupt the noise chain from source to transmission path. This can sometimes offer a way to modify or mask the noise so that it's more "pleasant "and less objectionable.

Most common interruption measures to reduce noise are:

- Damping:
  o Lessens the frequency or amplitude of the vibration
  o Target the mounting elements where vibration and noise is likely to be transmitted into the system
  o Can use Foam, elastomers, and viscous fluids. If possible, place damping material at the surface antinodes, where the deflection is maximum
- Noise Insulation (sound proofing):
  o Blocks or lessens noise from transmitting to outside a system
  o Target enclosure and system mounting elements

Insulation and damping must be considered separately, they are mutually exclusive.

Summary

We have seen that sounds and noise are highly dependent on the mechanical system the motor actuates, how the motor is driven electrically and what quality of sound the designer requires.
In a DC motor of any kind "zero sound" is not an option. Trying to mitigate sounds or noise after the design has been completed could be very difficult due to the diversity of motor types and complexity of noise sources. Therefore, designers of any system that use a motor should consider the vibration & acoustic outcome that their system requires.

If exacting quality of sound is required, only extensive testing will ensure an outcome and resolve any issues. Acoustic measurements and analytical work related to small DC motor noise sources can be complicated but may be necessary for certain types of applications.

The best option is to collaborate with a knowledgeable supplier or manufacturer to align on a desired outcome that is achievable and acceptable for your application.
Taking this approach and spending the time upfront could save hidden costs of redesign and heartache further down the line.

About Erntec
Erntec has been assisting in selection and design of small drive applications for over 30 years. Contact our experienced team to discuss your project requirements

Erntec Pty Ltd
www.erntec.com.au
Erntec electronics technologies <LOGO>
We think outside the box.

ERNTEC ELECTRONICS TECHNOLOGIES WE THINK OUTSIDE THE BOX.