A Review on Sustainable Woollen Felt for Soundproofing and Vibration Damping

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Abstract

At present, the commonly used building insulation materials are produced from synthetic materials including Foam, glass fibre, mineral wool and plastics. These types of materials can cause a diverse effect on the environment due to their non-renewable and non-disposable properties. Nowadays, awareness has been increasing in the use of environment-friendly and healthy materials. Several authors are studying natural sustainable and biodegradable fibres to develop thermal and acoustic insulation materials. due to their positive environmental effect, low carbon footprint and low hazardous effect to health. Wool felt acts as a highly effective, natural and sustainable material for both soundproofing and vibration damping, specializing in reducing noise, echo and reverberation through its porous, crimped fibre structure. It is commonly used as acoustic padding under machinery, in soundproof curtains, or within wall, floor and ceiling structures to dampen vibrations and improve acoustic comfort.

The felt was manufactured with traditional method uses heat, moisture (usually water and sometimes a mild acid solution) and pressure to interlock the microscopic scales on wool fibres, creating a dense, strong material. An FFT (Fast Fourier Transform) analyser used to analyse the vibration and sound signals f the weaving machines. It works by converting time-domain signals (e.g., vibration, sound) into the frequency domain using a digital algorithm to display signal amplitude and phase. It captures analog signals, digitizes them via an Analog-to-Digital Converter (ADC), breaks them down into individual sine wave components and displays the frequency spectrum. It is decided to use it primarily for machinery, protect equipment, reduce vibration and noise in industrial environments and provide cushioning

Keywords: porous absorber, sound absorption coefficient, safety and operational efficiency, Wet Felting, Dry Felting, Vibration Damping, Fast Fourier Transform Analyzer (FFTA), FFT Noise analysis

1.Introduction

Controlling nuisance is a key issue to have a healthy and pleasant environment. Our bodies treat sounds as nuisances when they exceed 65 dB of ambient sound pressure levels. Hearing loss is one of the serious health problems caused by nuisance. To combat the nuisance several sound absorbing materials were developed. Felt is one of such sound absorbers which have been in use since the nomadic age. It is a non-woven fabric made up of animal hairs or wool which may be from an animal, synthetic and plant fibres. To produce felt, the fibres are closely matted, compressed and then pressed together. For various applications different kinds of felt materials are used which differ in terms of fibre composition, colour, dimensions, thickness & density. Even today nomads in Central Asia as well as northern East Asia manufacture felt for their own uses. In the Asian countries & Middle East, these are employed for thermal insulation purposes and for reducing noise inside constructions. One can also find automotive & musical instruments made from them. In fact, the topmost layer of the interiors in cars which eliminates/ minimizes the effect caused due to vibrations from the engines, in your homes, the walls used as insulation materials along with construction materials are made up of them. The manufacturing process employed for the study of the felt is wet felting method where these animal hairs are used to manufacture them and hence on doing so they call the product as woollen felt. By spreading hot, soapy water over the stretched wool & pressing it against each other weaves these individual fibres into one fabric sheet known as a felt. Non-homogenous porous materials having sound absorbency properties for various applications for the control of noises are largely employed.

Viscous friction resulting from relative movement of solids and fluids is the most exploited and recognized way by which porous materials absorb sound. However, if the porous frame is viscoelastic, then there may be additional dissipative mechanisms. Achieving effective low-frequency absorption through this mechanism alone would require an impractically thick layer of material. It is well-known that a well-sized backing air gap can improve the low frequency response of passive sound absorbers based on porous materials or membranes. Elastic porous plates backed by an air cavity provide bending modes that contribute greatly to absorption at low frequencies. The coupling between airborne sound and bending vibrations in the plates strengthens with increasing flow resistivity. Air-gap of certain thickness can promote or prevent structural vibration depending on its thickness; however, it does not affect resonance frequencies believed to depend solely on the plate's mechanical properties, the way it is fixed and some micro structural characteristics (porosity, tortuosity, flow resistivity).

There has been a rise in knowledge about the importance of using nature friendly and safe commodities. These realizations have made individuals lean to what is nature and recyclable. This implies that there are several merits attached to recycling of textiles as far as insulating properties are concerned. Recycled materials can also be used to reduce the production of fibres through either animal or crop methods that emit the most significant quantities of CO_2 within the clothing industry. It is also a way of combating; on one hand, with the problem of environment pollution from land filled with fabric refuse; and on the other, of utilizing any such wasted resources to create something useful again. Many scholars have focused on exploring various organic commodities and fibres which could aid in the formulation of insulation materials meant for thermal comfort as well as noise abatement. This is because they are favourable to the environment, produce very little carbon emissions and pose minimal danger to human health.

2.Acoustic Engineering

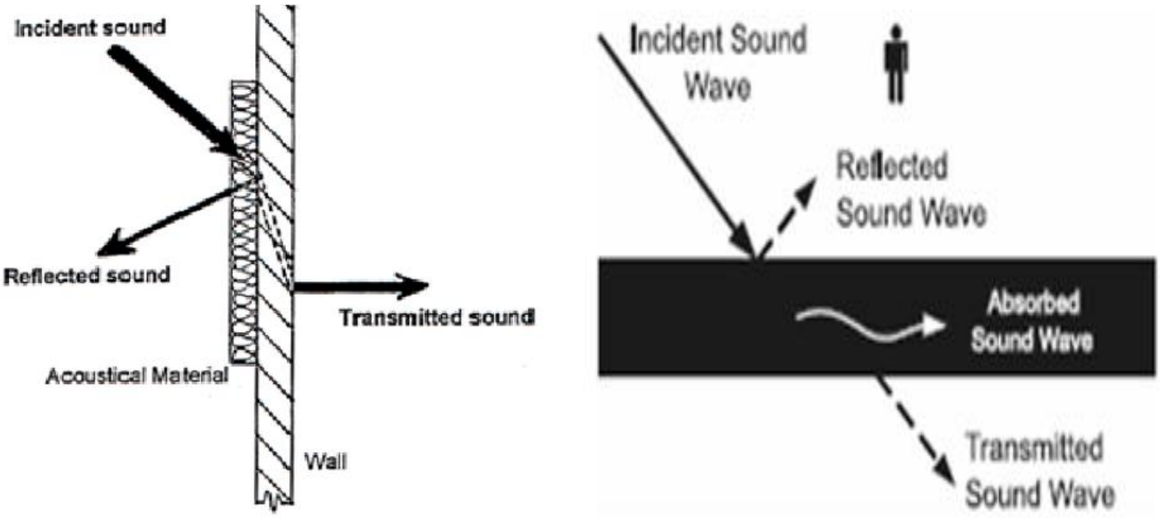


Figure 1. Sound absorption mechanism

Sound absorption materials are usually seen through their coefficient of sound absorption (α). This refers to the proportion of trapped acoustic energy within a given material and is valued from 0 to 1. If α = 0, this implies that there is no absorption but total reflection of the incident sound waves; on the other hand, α = 1 denotes complete absorption of all the sound waves or 100% sound absorption.

Table 1. Classification of sound

Sound absorption class	**Sound absorption coefficient**
A	0.90; 0.95; 1.00
B	0.80; 0.85
C	0.60; 0.65 0.70; 0.75;
D	0.30; 0.35; 0.40; 0.50; 0.55
E	0.15; 0.20; 0.25
F	0.00; 0.05; 0.10

Reference: ISO 11654:1997

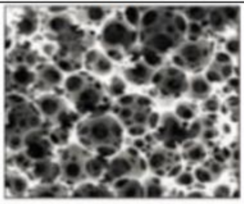
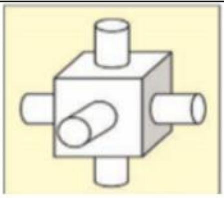
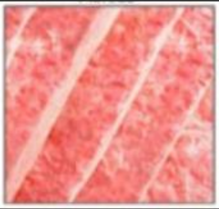
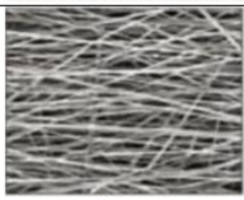
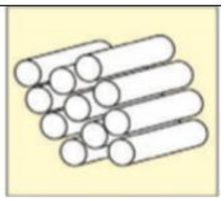
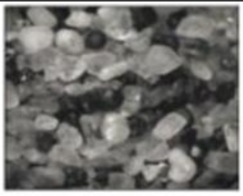
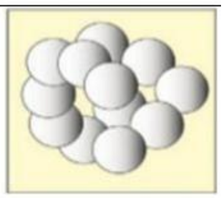
Frequency	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Value	0.80	1.00	1.00	1.00	0.90

Reference: EN ISO 11654

Methods to control Noise:

Porous absorber: Porous absorbers allow sound to travel through pores interconnected network leading to dissipation of sound energy. They work best at frequencies that are very well perceived by humans and lie within the middle to high range. These porous absorbers have been used to control noise levels in industries, vehicles, carriages, public address systems and music halls. It lowers level of reflected sound, reverberations or echoes. The different types of porous absorbers which is shown in Figure 2, include i) cellular, ii) granular and iii) fibrous materials. Cellular absorbers are created using foam of polyurethane or sometimes organic polyester material as well as aluminium or other metals. A sound-absorbing foam with an open structure enables air movement from one surface to another through interconnected pore passages. Polymers foam pose fire risk that produce burning poisonous gases while metals foam has high mechanical strength. Examples include panels made of wood chips; pervious road; and porous concrete among other common granular absorbers.

Table 2. Three configurations of natural fibres

Type	Configuration	Appearance by Visual	Structural by SEM	Molecular Shape
Cellular	Cubic cell with connecting pores			
Fibrous	Parallel fibers bundles			
Granular	Stacked spheres			

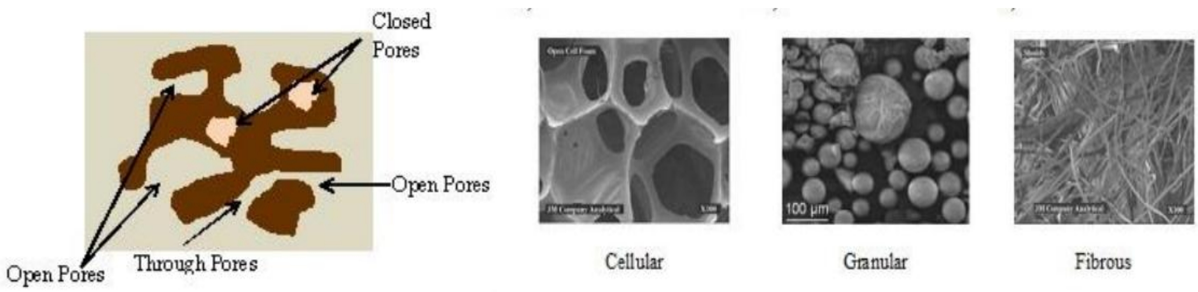


Figure 2. Types of porous absorbers

Textile materials can serve as porous absorbers. For example, feel, glass wool, rock wool, polymer foams and waste cloth fillers can be used in the production of porous absorbers which are based on textile fibre. This kind of absorber has a structure comprising spaces which enhance reflection within, trap sound energy and hence reduce the oscillation of air particles in that case air molecules rubbing against the material of absorber get damped. Nonetheless, they only work well with sounds that have a moderate to high frequency. As for the type of fibrous porous absorber, it depends on the nature of the raw materials used which could be either metallic, synthetic or natural. On top of that, certain non-corrosive metallic fibres like stainless steel, nickel, aluminium etc., may also serve as good noise absorbent in tough conditions.

Table 3. Pros and cons of various fibrous materials for soundproofing

Materials	Pros	Cons
Inorganic and metallic fibres	Good abrasion resistance, flame retardant, long service life, moisture resistance	Poor flexibility, heavy weight, poor formability
Synthetic fibres	Good recyclability, structural diversity, facile production process	Poor anti-static ability, easy to deformation when it is heated, low air permeability
Natural fibres	A wide range of raw materials, environmental-friendly, cheap	Poor flame retardancy, poor moisture resistance
Nanofibrous membranes	Light weight, thin thickness, good acoustic absorption	High production cost, low production efficiency, complicated preparation process

3. Wool Fibre:

Wool fibre is crimped; elastic and the fibre grow in staples or clusters as well as wool is a natural and renewable resource. The fundamental element of wool, which is an animal fibre, is protein (specifically keratin), that contains a polypeptide chain made up of amino acid side chains. The structural makeup of keratin involves a helical chain architecture wherein there are robust hydrogen bonds.

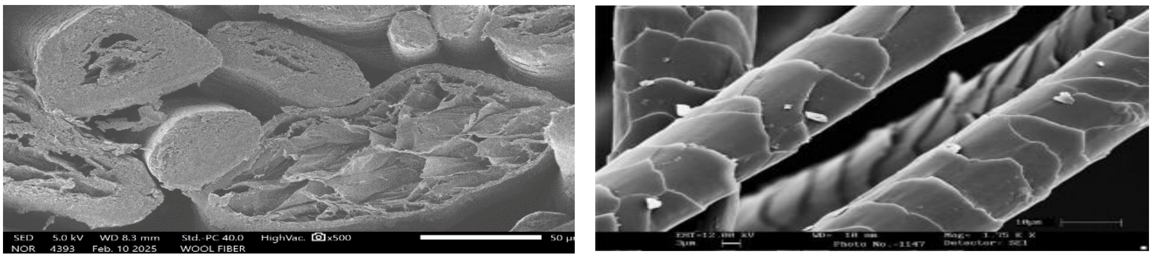


Figure 3. Wool fibre Morphology

On its outermost shown in Figure 3, the fibre appears to have overlapped scales that runs lengthwise from the cuticle. These scales offer a unique form of frictional resistance whereby friction across the scales is much higher than that along the scales. The diameter of wool fibres may vary from 10 to 30 microns while their length can be anywhere between 1 to 3 inches. It is through these microscopic barbs found on the surface of wool fibres that hooking together of fibres during felt-making is facilitated. Most of the time, these peculiar variations in thickness contribute towards manufacturing nonwovens that have high resistance to deformation and good insulation properties through trapped air in between fibres. It is possible to determine how well wool absorbs sound by examining its flow resistivity; this can also be done less accurately through analysis of density and fibre diameter. The intricate nature of the wool fibre traps enough packets of air thereby giving rise to an insulation property. This insulation property can be used in composite development for sound proofing goods. Compared with fibreglass and rockwool which are man-made mineral fibres, wool has much larger fibre diameters. Due to low density and high fibre diameter, wool is characterized by low resistance to airflow.

3.1 Wool felt:

Machinery in industrial plants produces constant vibration and noise, which can affect worker safety and operational efficiency. Woolen felt sheets are excellent for acoustic damping and vibration control. When installed under machinery, inside panels, or on floors, wool felts absorb shocks and reduce noise pollution, creating a safer and more comfortable work environment. Industrial operators also use felt sheets in transport vehicles, manufacturing robots and mechanical equipment where vibration can lead to premature wear or misalignment. The cushioning effect of wool felts helps extend equipment life and improve precision in high-performance industrial setups. Wool felt is a fabric known for its beauty and functionality. Felt is a matted fabric made of fibres. It can be made from wool or another animal hair but nowadays it is also made from synthetic fibres like acrylic. Wool felt has many special properties: it is highly fire resistant, it can absorb sound very well and it can take up a lot of moisture. Felt is unique among textiles because it is neither woven nor knitted. The fibres in a piece of felt are held together by a combination of heat, water and pressure– there is no way to undo this "mating" of the fibres by simply reversing the process. This means that felt does not fray or unravel at the edges like woven or knitted fabrics do. You can cut it into different shapes and sew it without worrying about your stitches coming undone.

Archaeological evidence suggests that felt is the world's oldest textile! Bits of felt dated to c. 6500 BC have been found in Central Asia. It is likely that humans began making felt by accident when animal fibres were compressed under heat and pressure. Various cultures have myths about how felt was invented. In Western tradition it is said to have been discovered by Saint Clement or Saint James when they took their shoes off after walking for a while and found fibres that had formed under the heat and pressure of their bodies. For most of its history felt was made from natural fibres– wool being the most common source. When synthetic fibres were invented in the early 20th century, manufacturers began making felt from acrylic. Because wool felt is naturally fire retardant (acrylic felt catches fire easily) and of higher quality, many people still prefer wool felt over synthetic.

3.2 Type of felts

Many varieties of woollen and fur felts have been innovated by textile artisans throughout history. However, in the recent past, there has been a departure from this trend by fabric producers who are now creating felt using synthetic materials instead of relying on natural animal fibres as it used to be done before.

1.Wool felt

Felt remains a widely used material that is commonly produced by textile artisans employing wool gotten from sheep or other wool-producing animals. Wool felt is not only beautiful but also has the same properties as its base fiber; absorbent, fire resistant with great insulation.

Figure 4. Wool felt

2.Fur felt

Beaver pelts are still employed by certain fabric producers in the production of felt headgear and related items. Although it was very popular before the animal rights era, fur felt has come down in appeal but is still appreciated for being very durable as well as easily molded. Fur can also be used for making fur felt although it may not be limited to the fur of beavers alone, but regardless of the source, the making of fur felt calls for the death of animals that have fur on them.

Figure 5. Fur felt

3.Acrylic felt

In the last hundred years, there has been a rise in the use of acrylic felt. It is cost-effective to make than wool and gives a cheaper option for conventional felt which is known for being comfortable. Nevertheless, acrylic felt differs from wool or fur felt because it is very combustible and irritating in close contact with the skin.

Figure 6. Acrylic felt

4.Rayon felt

Rayon felt is a fabric that is often utilized within the industry and hospitals because it is hydrophilic like wool felt. It is possible to fashion different kinds of insulation material from rayon felt, which is a big plus for this fabric. Nonetheless, just like any other artificial fabric polymer, rayon does not break down naturally in the environment but is rather a pollutant.

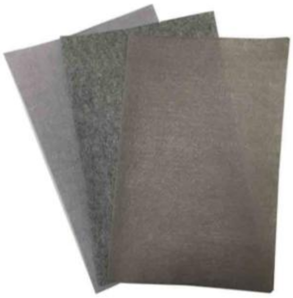


Figure 7. Rayon felt

5.Pressed felt

The oldest and most popular felt is pressed felt. This kind of felt which comes in sheets for sale but can be fashioned into different articles for consumers, industries as well as hospitals is made by amalgamating textile fibres together using a combination of water, heat and pressure to form a mat.

Figure 8. Pressed felt

6.Needled felt

Specialized needles are employed by artisans to create needle felt toy characters and different kinds of three dimensional articles. The kind of felt used here is the non-insulating or non-industrial type, with the greater majority of needle felt being earmarked for decorations.

Figure 9. Needled felt

7.Woven felt

Textile producers make woven felt which is one of the felt cloth varieties through subjecting the pre- woven materials to temperatures, moisture and compression. The outcome is a closely packed fabric that contains high insulation but can be very slim as compared to the felt that is pressed.

Figure 10. Woven felt

Felt making is slightly different when there is a combination of wool and acrylic or other textile fibres. To begin, raw fibres are obtained either from wool-bearing animals or by spinning dissolved polymers for artificial fibres such as acrylic. After this, the various fibres are blended. A cylindrical steel drum with nails is used to pull out the fibres. The next step involves passing the fibres through a carding machine where they are carded into a loose web with evenly spaced fibres. A cross-lapper combines several webs into one roll but before it is done there will first be four such rolls piled one over the other in a batt. The next step is to harden the felting material by exposing it to heat and moisture and finishing off with shrinking under heat pressure and moisture. During the last phase of manufacture most felt producers use sulfuric acid and once the material reaches the required dimensions they wash & neutralize the acid using warm water and soda ash. Any defects on the finished felt fabric are ironed out by an industrial machine with rollers.

The end product is now ready for other secondary processes like dying, cutting, molding among others or can be sold as whole sheets. The main use for felt today remains to be in the manufacture of warm hats & insulation for boots among other applications that require thick material which does not let air through and provides optimum comfort such as wound dressing. If worn, the insulative wool material will neither be stiff nor prick the skin because it has been processed enough through felting, so it is stiff but flexible with piles on both sides that feel nice on any kind of skin whether thin or thick. Knitted or woven wool are less efficient as barriers of the cold!

3.3 Manufacturing of wool felt

Wool felt is manufactured primarily through two industrial processes: **wet felting** (or pressed felt) and **needle felting** (or dry felting), both of which involve tangling and compacting fibres without knitting or weaving.

Wet Felting (Pressed Felt)

This traditional method uses heat, moisture (usually water and sometimes a mild acid solution) and pressure to interlock the microscopic scales on wool fibres, creating a dense, strong material.

- **Preparation**: Raw wool is cleaned to remove dirt, grease and plant matter, then blended with other fibres if needed. The fibres are then carded (combed) to align them into a loose web and multiple layers of this web are combined into a thick mat called a "batt".
- **Hardening**: The batts are subjected to steam and passed through a plate hardener or roller machine, which applies vibrational pressure and heat, causing the fibres to start matting together and shrinking in width.
- **Fulling**: The felt is then processed in a fulling machine, which uses heavy rollers and a hot water/sulfuric acid solution to shrink the material further in length, making it denser and thicker.
- **Finishing**: The acid residue is neutralized with a soda ash solution and the felt is washed, dried and then pressed or ironed to ensure a consistent thickness and smooth surface. It can also be dyed during this stage.

Needle Felting (Dry Felting)

This dry method uses a mechanical process to interlock the fibres and does not require water or chemicals, though some needled felts may be pressed with heat afterward for added density.

- **Preparation**: Similar to the wet process, fibres are cleaned, blended and carded into a batt.
- **Needling**: The batt is fed into a needle loom machine equipped with thousands of special barbed needles. The repeated, rapid punching of these needles physically pushes and tangles the fibres together, creating a cohesive, non-woven fabric.
- **Finishing**: The resulting fabric can then be finished, which may include additional pressing for specific density requirements, trimming the edges, or other treatments

Sustainable felt:

Among the most biodegradable materials across the globe are wool and fur felt. These kinds of felt may have some environmental problems with regard to land use and taking care of animals. It is considered cruel and barbaric to trap animals for their fur nowadays, although sometimes wool production can be cruel too and result in either pollution or soil erosion. Nevertheless, natural fibres are always eco-friendlier compared to artificial fabrics. The production processes of both acrylic and rayon involve highly toxic, caustic agents that endanger workers' health in the textile industry. Very occasionally do textile manufacturers discharge these chemicals in the right manner; most of them end up contaminating the environment. Unlike other synthetic fabrics, acrylic and rayon felts are infrequently washed although these synthetic felt materials can still add to microfiber pollution while being used. Being non-biodegradable materials, when thrown away, acrylic and rayon felts either accumulate in landfills or add to plastic pollution.

3.4 Applications

Wool felt acts as a highly effective, natural and sustainable material for both soundproofing and vibration damping, specializing in reducing noise, echo and reverberation through its porous, crimped fibre structure. It is commonly used as acoustic padding under machinery, in soundproof curtains, or within wall, floor and ceiling structures to dampen vibrations and **improve acoustic comfort.**

3.5 Key Features and Benefits

- Sound Absorption: Wool fibres trap sound energy, reducing echoes in rooms and decreasing sound transfer.
- Vibration Damping: High-density, needle-punched wool felt is effective for insulating industrial machinery, pads and gaskets to absorb shock.
- Versatile Applications: Used in factories for machine padding, or in residential spaces for acoustic panels, flooring underlayment and soundproof curtains.
- Durable & Eco-Friendly: It is a durable material that often offers good compression recovery and is environmentally sustainable.
- Thermal Insulation: Beyond sound, wool regulates temperature and provides insulation benefits.

3.6 Common Uses

- Machinery Pads: Placed under heavy, vibrating equipment to reduce noise and extend machine life.
- Acoustic Panels/Wall Coverings: Used in studios and offices for sound absorption.
- Soundproofing: Installed within walls or as underlayment to block sound transmission between floors.
- Industrial Gaskets: Custom-cut to dampen vibrations in machinery components.

4. Vibration Engineering

In mechanics, vibration refers to oscillatory movement around a central point of rest (derived from Latin vibrāre meaning “to shake”). It can be deterministic when the oscillations are exactly definable (as in the case with a pendulum that swings), or random in nature if only statistical analysis can be made of them (like how a tire moves on a gravel road). These two falls under acoustics and hence are intertwined–studies on sound and vibration. Vibrations produce sound known as pressure waves and on structures like vocal cords; while this wave of pressure can lead to vibrations in other structures such as the eardrum. As such, reduction of noise attempts is very closely associated with vibration issues. When an unbalanced force acts on a machine and creates a motion that repeats itself over time, we say that there is vibration or oscillation. For a machine to function properly at its specified speeds and other dynamic movements like feed, rapid etc., it requires vibrations.

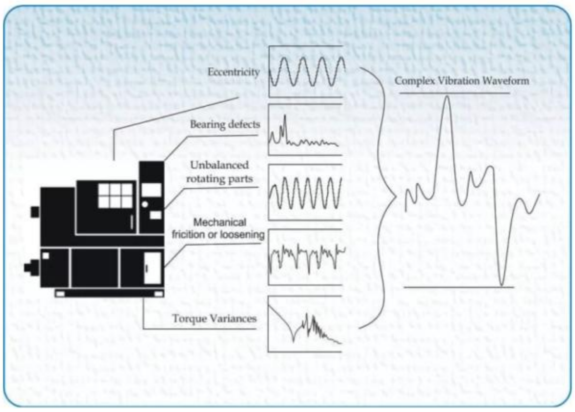


Figure 11. Complex vibration waveform

Vibrations in textile machines, particularly in high-speed spinning and weaving, are caused by rotating parts, reciprocating motions (e.g., picking mechanisms) and varying mass, leading to noise, machine fatigue and reduced fabric quality. Mitigation involves using anti-vibration mounts, dynamic balancing and viscous dampeners to stabilize, reduce noise and increase lifespan.

4.1 Wool felt for vibration damping

Wool felt is a highly effective, natural material for vibration damping, prized for its dense, fibrous and elastic structure that absorbs and dissipates mechanical energy. It is primarily used to isolate machinery, protect equipment, reduce noise in industrial environments and provide cushioning in automotive and construction applications.

4.2 Design Criteria

To achieve maximum efficiency, one should use the least area of the most compressible felt under a load that is just sustainable by the felt without significantly deforming it. Felt pads work very well in isolating machinery and therefore they are normally seen in isolation of machines either directly placed on them or with glue applied.

The felt of soft nature and in maximum thickness can give the greatest isolation effectiveness when employed as a vibration-isolation material provided it is subjected to a static load that it can resist without being excessively compressed or losing its structural integrity. It also has great damping effect and this makes it very suitable in damping or reducing amplitudes of vibration particularly at resonance. The amplification factor at resonance for this kind of felt is nearly constant at different amplitudes and has a load value of about 4. The felt mounting should be at least 1 to 2. 5cm (1/2 to 1 inch) thick, occupy an area equal to about 5 % of the total base area in case the machine rests on flat bed and it should be used for general purposes. In cases where the vibration levels are moderate, there is no need to bond the felt and machine together.

4.3 Key Causes and Effects of Textile Machine Vibrations

- High-Speed Operation: High RPMs in machines like spinning frames cause vibrations that threaten productivity and create high-noise environments.
- Mass Variation: In winding operations, the increasing mass of the textile material on the bobbin causes, changes in rotational dynamics.

- Mechanical Components: In looms, the picking mechanism, shedding system and beat-up motion are primary sources of noise (often over 90 dB).
- Fatigue and Damage: Uncontrolled vibration causes fatigue failure of components and reduces machine lifespan.

4.4 Vibration Analysis and Mitigation

- Analysis Methods: FFT (Fast Fourier Transform) analysers and sensors are used to monitor machine conditions, evaluate frequency response and identify damaging vibration frequencies.
- Isolation Mounts: Dynemech anti-vibration mounts and spring/viscous dampers prevent floor vibrations and improve machine stability.
- Damping Material: Viscoelastic materials, including rubber, are applied to reduce the force transmissibility in components like weaving looms.
- Simulation: Software like Mathematica or Math Modelica is used to simulate and optimize machine components to minimize vibrations.

Figure 12. Vibration damping solutions for textile machines

4.5 FFT (Fast Fourier Transform) Analyzer

The purpose of the FFT Analyzer is to gauge vibrations by converting them into displacement, velocity as well acceleration, all expressed within the frequency domain. Many fields rely on FFT analysis as their prime method for processing signals. It does this transformation using a Fast Fourier Transform also abbreviated as FFT.

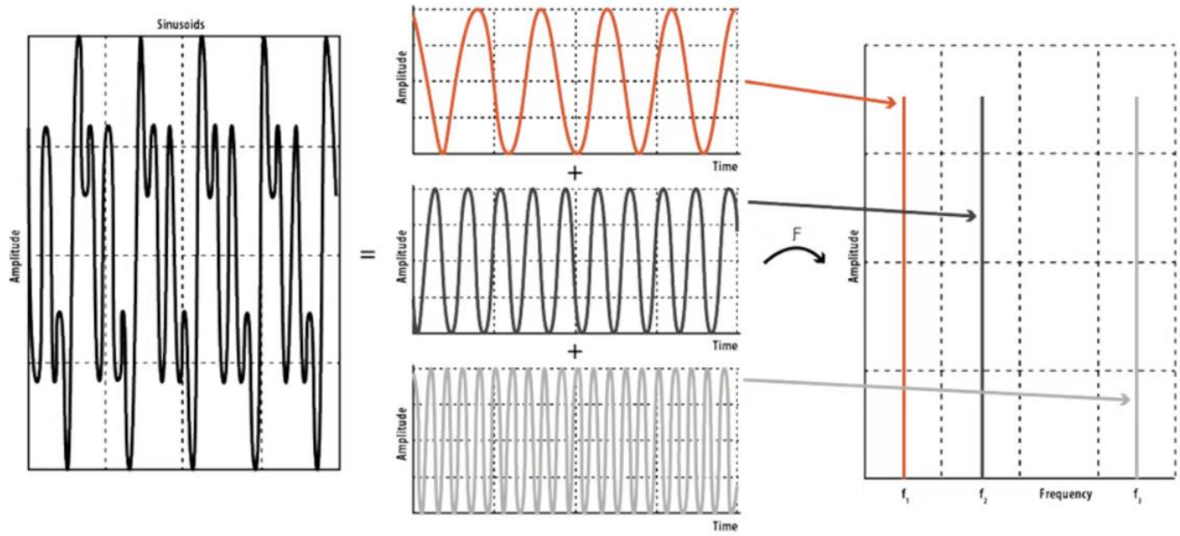


Figure 13. Waveform data

The time domain data alone is limiting in terms of analyzing various properties of signals but this can be enhanced through FFT analysis. With FFT analysis, many signal characteristics which would have otherwise taken much time can now be studied intensively. Signal characteristics in the frequency domain are made up of independent frequency components while in the time domain they are described as a single waveform containing all factors added together. It is powerful tool that converts time domains complex signals to frequency domains, showing their constituent frequencies (like pitches in sound or vibration patterns) as a spectrum, making it essential for audio analysis, machinery diagnostics (vibration), telecommunications and more, offering high resolution and speed to identify hidden characteristics in signals. It's used in hardware devices and software (like MATLAB) to analyse sound levels, detect machine faults and process various sensor data. It is a specialized instrument that converts time-domain signals (raw data over time) into a frequency-domain representation (a spectrum). It uses the FFT algorithm, for calculating DFT (Discrete Fourier Transform) to break down complex waveforms into their individual sine and cosine wave components.

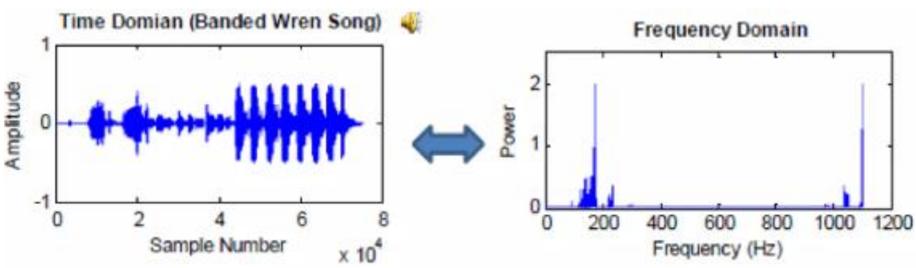


Figure 14. Time domain conversion to frequency domain

An FFT (Fast Fourier Transform) analyser works by converting time-domain signals (e.g., vibration, sound) into the frequency domain using a digital algorithm to display signal amplitude and phase. It captures analog signals, digitizes them via an Analog-to-Digital Converter (ADC), breaks them down into individual sine wave components and displays the frequency spectrum.

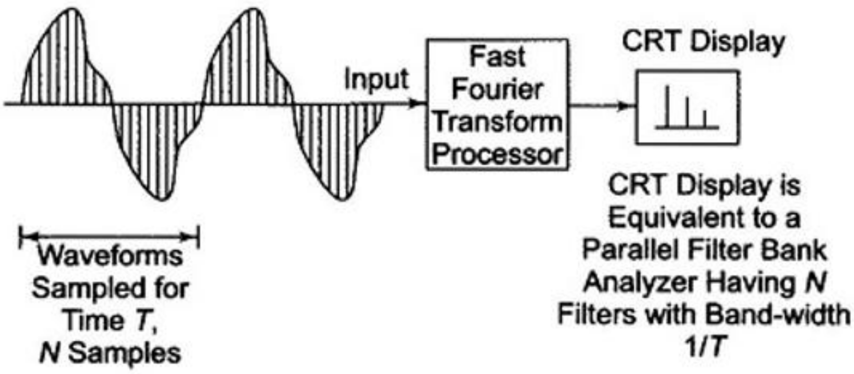


Figure 15. Operations of FFT Analyzer

For obtaining time domain information from sensors through Fast Fourier Transform (FFT), data acquisition systems (DAQ) are employed. In order for a computer and software to handle and study the information obtained from transducers, it needs to be digitized. This is because sensors combined with specialized DAQ units linked with PCs running FFT analysis programs is the most common choice. The sample rate of the digital temporal signals is specified by the ADC (Analog to Digital converter) of the DAQ system.

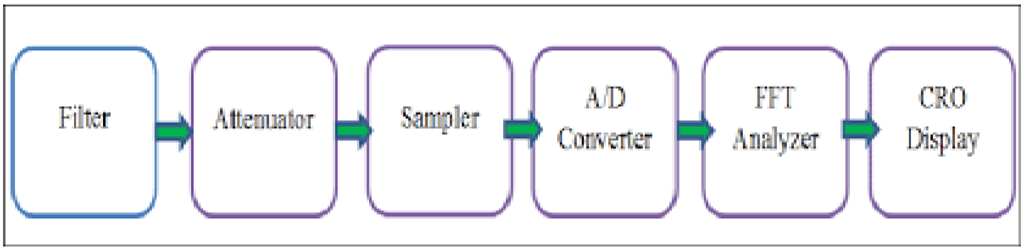


Figure 16. Block diagram of FFT Analyzer

Figure 17. FFT analyzer experimental setup

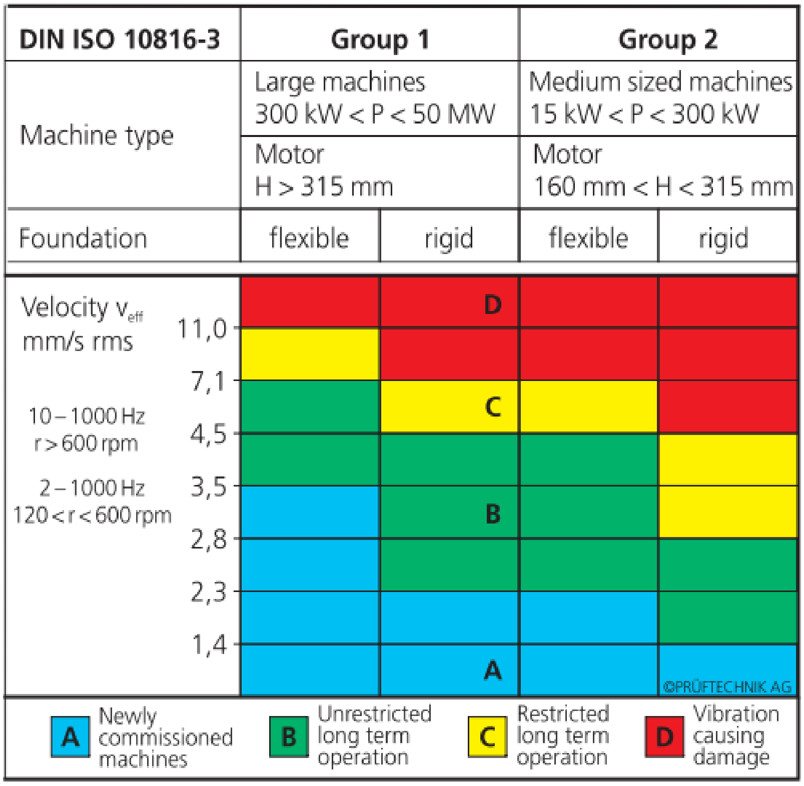


Figure 18. ISO Standard: Vibration severity

5. FFT Noise analysis

Fast Fourier Transform (FFT) analysis in sound converts time domain signals into frequency domain spectra which is shown in Figure 19. It decomposes complex, combined audio waveforms into individual, constituent sine wave frequencies, allowing for the identification of pitch, tone and harmonic content. FFT is essential for noise detection, vibration analysis and audio quality control.

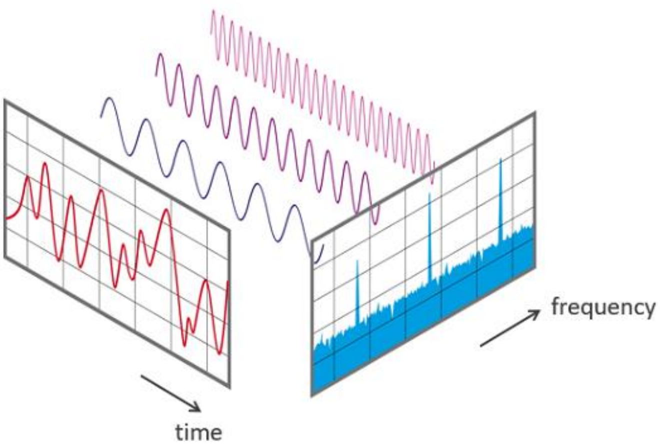


Figure 19. Time domain vs Frequency domain

The DED process involved analyzing various sound sources using the Fast Fourier Transform (FFT) as shown in the below Figure 20.: (a) frequency plot with a logarithmic scale and (b) magnitude plot with a logarithmic scale.

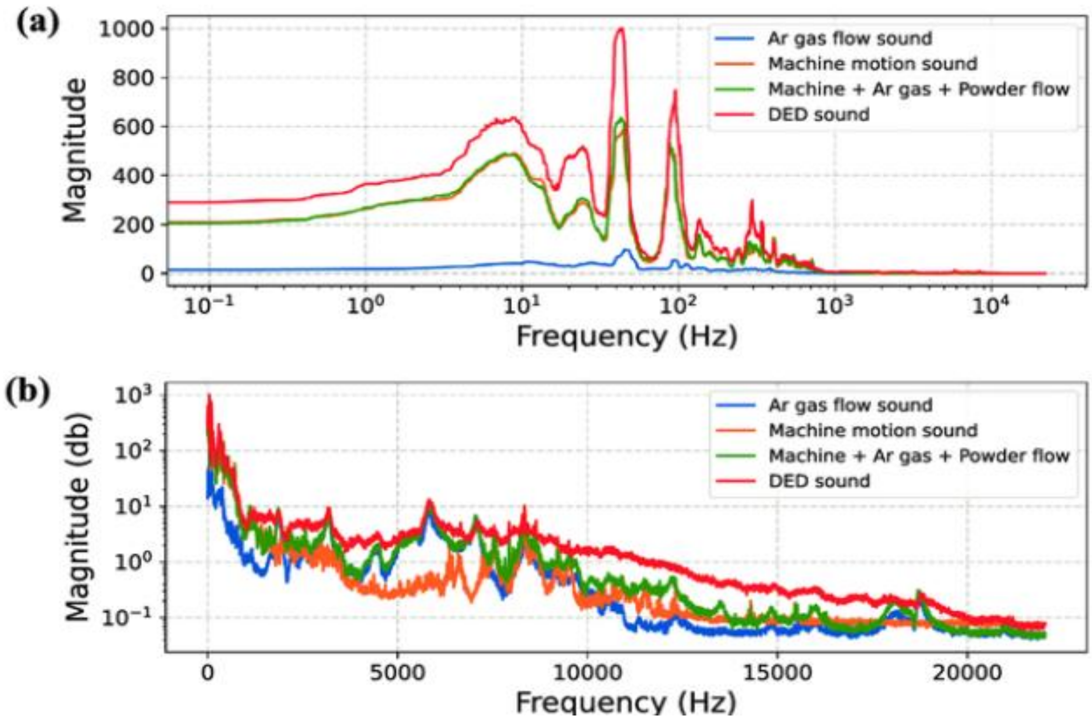


Figure 20. (a) frequency plot with a logarithmic scale and (b) magnitude plot with a logarithmic scale

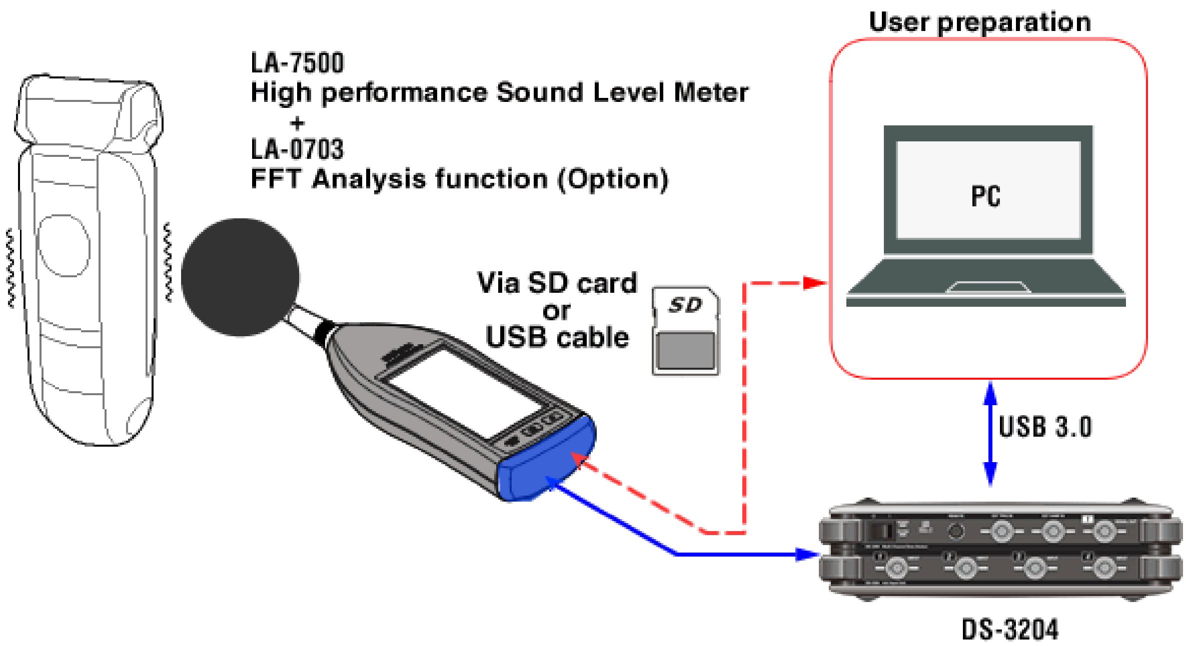


Figure 21. Performing FFT analysis of the noise which is generated by home appliance

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