



# Finite Element Analysis of Constrained Layer Damping for Vibration of Robotic Arm

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**Abstract:** This study investigates vibration reduction in a robotic arm using constrained layer damping (CLD) method. A three-dimensional finite element model of the top arm section was developed using ANSYS, with Aluminum 6061 as the base material. Modal analysis was performed to determine natural frequencies and mode shapes, followed by harmonic response analysis under a constant excitation force of 10 N over a frequency range of 0–3.5 KHz.

**Keywords:** Restrained Layer Damping, Robot Arm, Modal evaluation, Harmonic reaction, Finite element analysis, Vibration discount, Viscoelastic materials, Structural Dynamics



## INTRODUCTION

Robotic arms are broadly utilized in automated structures where precision and repeatability are important. To improve performance and decrease electricity consumption, those structures are designed with reduced weight. However, lightweight construction ends in decreased stiffness, making the shape extra sensitive to vibration.

Vibration in robot arms takes place due to dynamic hundreds, rapid motion, and outside disturbances. Whilst the excitation frequency strategies the herbal frequency of the shape, resonance takes place, resulting in a pointy growth in vibration amplitude. This situation ends in loss of accuracy, instability, and viable structural failure.

The dynamic response of a shape is ruled by way of mass, stiffness, and damping. Even as mass and stiffness outline natural frequencies, damping controls vibration amplitude. Maximum light-weight structures have low inherent damping, making external damping methods necessary. Confined layer damping (CLD) is a powerful passive technique wherein a viscoelastic layer is added among structural layers. During vibration, shear deformation takes place inside the viscoelastic layer, converting mechanical electricity into warmth and lowering vibration amplitude.

On this paintings, a finite element technique is used to study vibration conduct and examine the overall performance of various damping materials below identical situations. The objective is to determine the handiest fabric and configuration for vibration reduction

In addition to material selection, geometric configuration and boundary conditions also play a good sized role within the vibration response of robotic structures. The cantilever nature of robotpalms makes them extra liable to bending vibrations, specially at the free end wherein maximum displacement occurs. This makes it essential to pick out crucial areas where vibration is dominant and follow appropriate damping techniques.

Modal analysis is an vital step in understanding the inherent dynamic traits of the structure. It offers records about herbal frequencies and corresponding mode shapes, which enables in identifying resonance conditions. With the aid of analyzing these parameters, it becomes possible to expect the behavior of the shape underneath unique operating situations.

Harmonic response analysis similarly extends this knowledge by means of comparing the reaction of the structure under various excitation frequencies. It facilitates in identifying the amplitude of vibration at resonance and assessing the effectiveness of damping techniques. This evaluation is specifically beneficial in figuring out how special materials influence vibration discount.

The performance of confined layer damping depends no longer simplest at the kind of viscoelastic fabric used however also on its thickness and site. Materials with better energy dissipation functionality offer higher damping performance. But, growing thickness does no longer always bring about proportional improvement, because the interplay among layers influences the general reaction.

Consequently, a scientific assessment of different damping materials underneath identical conditions is important to become aware of the maximum efficient solution. On this examine, Neoprene,

Butyl Rubber, and PU Elastomer are taken into consideration as damping substances, and their overall performance is evaluated using finite element analysis.

The outcome of this work affords insights into the choice of appropriate damping materials for robotic packages. It additionally contributes to the layout of lightweight structures with progressed vibration manipulate, making sure higher accuracy, stability, and structural reliability.

### 1. LITERATURE REVIEW

Vibration manage in mechanical systems has been substantially studied because of its significance in enhancing overall performance and durability. Passive damping strategies are broadly used because of their simplicity and reliability. Restricted layer damping is one of the simplest passive techniques for vibration discount. It utilizes viscoelastic substances that dissipate electricity through shear deformation. Previous research have confirmed the effectiveness of CLD in beam and plate systems.



Viscoelastic materials which includes neoprene, butyl rubber, and polyurethane elastomers are usually utilized in damping programs. Their effectiveness depends on material houses such as modulus, damping issue, and thickness.

Finite element evaluation has grow to be a widespread tool for vibration research. Modal evaluation is used to determine herbal frequencies and mode shapes, at the same time as harmonic analysis evaluates response under dynamic loading.

maximum existing studies recognition on unmarried-cloth analysis or distinct structural configurations. Comparative evaluation of a couple of materials below same situations is restricted. This take a look at addresses this hole by way of comparing unique damping materials with the identical geometry and loading conditions. Numerous researchers investigated the have an impact on of damping substances on vibration reduction in light-weight structures. it's been determined that substances with higher viscoelastic residences provide higher electricity dissipation, in particular close to resonance situations. research additionally suggest that the location of the damping layer in areas of maximum deformation considerably improves effectiveness.

similarly to fabric houses, the thickness of the damping layer plays an important function in vibration control. increasing thickness typically improves damping performance due to elevated shear deformation within the viscoelastic layer. but, past a positive limit, the development will become marginal, indicating that material characteristics dominate over thickness variation.

current advancements in computational methods have enabled correct prediction of vibration behavior the use of finite element techniques. these techniques allow certain analysis of structural response with out the need for big experimental setups. As a result, numerical studies have turn out to be a desired method for evaluating damping overall performance in engineering programs.

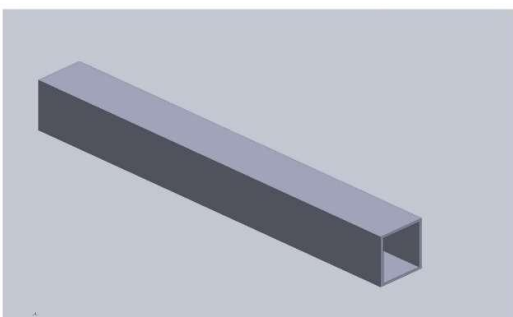
some research have additionally targeted on optimizing damping configurations by way of combining one-of-a-kind materials or the use of multi-layer arrangements. these approaches aim to beautify electricity dissipation whilst keeping structural performance. however, such configurations frequently boom complexity and value.

no matter the to be had studies, there may be still a need for systematic comparison of commonly used viscoelastic substances underneath identical conditions. this is in particular vital for realistic packages which includes robotic palms, where both weight and vibration manage are critical.

consequently, the present paintings specializes in comparing the performance of selected damping substances the usage of a steady modeling technique. The effects provide a clean understanding of how cloth houses and thickness affect vibration reduction, which can be beneficial for designing efficient damping answers in mechanical structures.

## 2. METHODOLOGY

A three-dimensional version of the pinnacle arm segment of a robot arm was advanced with a period of 250 mm and a rectangular go-segment of 40 mm × 30 mm. The shape changed into modeled as hollow to reduce weight while preserving energy.



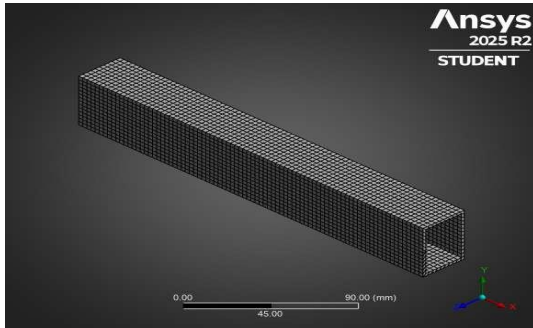
Aluminium 6061 turned into used because the base cloth because of its high power-to-weight ratio. The model become imported into ANSYS Workbench for analysis.

The geometry became discretized the usage of finite detail meshing. a elegant mesh became utilized in regions of



excessive deformation to enhance accuracy. right mesh first-class turned into ensured to reap reliable results.

throughout harmonic analysis, the excitation frequency became numerous over the specified range to perceive resonance situations and height reaction. The deformation reaction of the shape become recorded at every frequency point to assess the effectiveness of damping.



Boundary conditions have been applied through fixing one stop of the shape, representing a cantilever configuration. A harmonic load of 10 N became implemented on the unfastened quit in the vertical route.

Modal evaluation changed into carried out to determine natural frequencies and mode shapes. Harmonic reaction analysis turned into finished over a frequency range of 0–3.5 kHz.

restrained layer damping become implemented the usage of Neoprene, Butyl Rubber, and PU Elastomer with thicknesses of 1 mm and 2 mm. All instances had been analyzed below equal situations. The choice of element kind and mesh density plays a crucial role in acquiring accurate simulation outcomes. A appropriate element length become selected to balance computational time and solution accuracy. Mesh refinement was completed near the fixed cease and regions of expected maximum deformation to capture pressure and displacement versions efficaciously.

Material	Density(kg/m <sup>3</sup> )	Young's modulus(MPa)	Poission's ratio
Aluminium	2700	$6.9 \times 10^{10}$	0.33
Neoprene	1100	$7 \times 10^6$	0.49
Butyl rubber	920	$3 \times 10^6$	0.49
Pu elastomer	1200	$2.5 \times 10^7$	0.48

Fabric residences together with young's modulus, density, and Poisson's ratio had been defined as it should be in the simulation surroundings to make certain realistic behaviour of the structure. The viscoelastic substances used for damping had been assigned appropriate mechanical residences to represent their electricity dissipation characteristics.

The cantilever boundary circumstance represents the real running situation of the robot arm, in which one give up is rigidly fixed while the alternative cease is unfastened to vibrate. This setup allows clean observation of bending conduct and vibration reaction alongside the duration of the shape. For comparative analysis, the undamped case turned into first evaluated to set up a baseline. subsequently, damping layers with exceptional substances and thicknesses were carried out, and their responses had been in comparison under identical loading and boundary conditions. This method ensures a constant and reliable comparison of damping performance.

The overall technique provides a systematic framework to examine vibration characteristics and compare the effectiveness of restrained layer damping in lowering vibration amplitude in robot systems.

### 3. MODAL ANALYSIS

Modal evaluation gives the natural frequencies and corresponding mode shapes of the structure. those parameters constitute the inherent dynamic characteristics of the robot arm.

the first natural frequency is discovered in the range of 0.5–0.6 kHz. that is the maximum essential frequency as resonance is possibly to arise on this vicinity.

the primary mode shape shows bending deformation with most displacement at the unfastened quit. better modes exhibit more complicated deformation styles however have less influence on typical vibration conduct.

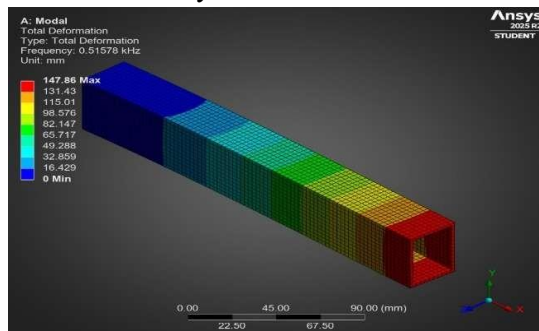
The addition of damping layers does not appreciably regulate the mode shapes. This shows that CLD commonly impacts vibration amplitude instead of converting structural stiffness.

The identity of herbal frequencies is vital to avoid working conditions that may result in resonance. for the reason that first mode has the very best impact on the overall dynamic reaction, it is taken into consideration the maximum critical for vibration evaluation. The deformation sample determined in this mode confirms that the shape behaves like a cantilever beam, with maximum displacement taking place on the free stop and minimal at the fixed help.

higher mode shapes represent greater complicated vibration styles related to extra curvature alongside the duration of the shape. even though these modes occur at higher frequencies, their contribution to the overall vibration reaction is comparatively decrease underneath regular working situations.

The assessment of modal effects with and without damping layers suggests that the presence of viscoelastic substances does now not extensively change the herbal frequencies. this is because the stiffness of the base shape stays dominant, and the added damping layers basically make a contribution to energy dissipation in place of stiffness change.

This commentary confirms that restrained layer damping is powerful in decreasing vibration amplitude with out changing the fundamental dynamic traits of the shape. consequently, CLD can be implemented with out affecting the authentic layout conduct of the robot arm.



#### Mode 1

The modal evaluation consequences function a foundation for harmonic reaction evaluation, wherein the effect of damping on vibration amplitude at distinct frequencies is evaluated. expertise those modal characteristics is critical for designing effective vibration control techniques.

Case	Mode	Decrease
No cld	515	0%
Neoprene	508	1.03%
Butyl rubber	500	2.33%
Pu elastomer	510	1.08%

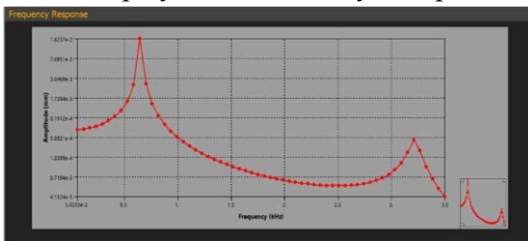
#### 4. HARMONIC RESPONSE ANALYSIS

Harmonic evaluation become completed to assess the response of the shape underneath dynamic loading. The undamped shape shows a pointy height in deformation on the resonance frequency. The advent of restrained layer damping reduces the peak amplitude considerably. The discount varies relying at the material used.

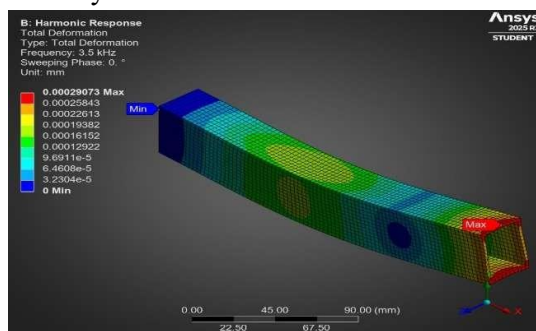
the various substances, Butyl Rubber shows the best discount in vibration amplitude because of its advanced viscoelastic properties. Neoprene shows mild performance, whilst PU Elastomer affords relatively lower damping.

increasing the thickness from 1 mm to 2 mm effects in similarly reduction in vibration. but, the improvement isn't always proportional, indicating that material homes are extra influential than thickness.

The harmonic reaction curve actually shows that the maximum deformation happens near the primary herbal frequency, confirming the presence of resonance. inside the undamped condition, the height is sharp and slim, which displays low electricity dissipation within the machine.



With the application of restrained layer damping, the height amplitude is reduced and the reaction curve becomes smoother. This shows that the viscoelastic layer effectively dissipates vibrational electricity and reduces the severity of resonance.



many of the materials considered, Butyl Rubber demonstrates advanced damping conduct due to its higher energy absorption functionality and higher viscoelastic traits. The discount in top amplitude for Butyl Rubber is significantly better in comparison to the alternative substances, making it the best choice on this observe.

Neoprene presents mild damping overall performance, decreasing vibration to a extensive extent, whilst PU Elastomer suggests relatively decrease effectiveness because of its decrease damping capability. The variations in performance are mainly attributed to variations in material houses along with damping aspect and stiffness.

The effect of thickness is also evident from the consequences. increasing the thickness enhances shear deformation within the viscoelastic layer, leading to improved strength dissipation. but, the development isn't always linear, indicating that beyond a sure thickness, additional fabric does now not contribute considerably to vibration discount.

Those observations verify that while thickness has an influence, the selection of cloth is the dominant issue in reaching powerful vibration manage. The harmonic analysis results provide a clean information of the way different damping configurations affect the dynamic response of the structure.



Case	Material	Amplitude	Deduction
1	No cld	$1.62 \times 10^{-2}$	0%
2	Neoprene	$5.38 \times 10^{-3}$	66.8%
3	Butyl rubber	$4.69 \times 10^{-3}$	71%
4	Pu elastomer	$6.00 \times 10^{-3}$	68%

## 5. RESULTS AND DISCUSSION

The results clearly exhibit that restrained layer damping is powerful in reducing vibration in robotic systems. The reduction in height amplitude confirms the potential of viscoelastic materials to expend strength.

Butyl Rubber suggests the exceptional overall performance most of the materials studied. this is because of its better damping ability and strength absorption characteristics.

The impact of thickness is great however restrained. increasing thickness improves damping, but past a sure point, the improvement will become marginal.

The consequences additionally imply that the place and residences of the damping material are essential elements in reaching powerful vibration discount.

The comparison between exclusive materials highlights the importance of viscoelastic conduct in vibration manipulate applications. substances with higher inner damping traits are extra effective in converting mechanical electricity into heat, thereby decreasing the amplitude of vibration. This explains the superior overall performance located in Butyl Rubber as compared to the alternative materials.

The fashion located in the outcomes shows that surely growing the thickness of the damping layer is not sufficient to acquire most vibration discount. instead, an gold standard aggregate of fabric properties and layer thickness is required for effective damping performance.

every other crucial remark is that the damping layer is most effective whilst applied in areas of excessive deformation. since most displacement takes place near the free cease of the cantilever structure, setting damping cloth in this vicinity enhances energy dissipation and improves ordinary performance.

The consistency of consequences throughout special cases confirms the reliability of the finite detail technique used in this have a look at. The numerical evaluation provides a clean understanding of the have an impact on of various parameters on vibration behavior.

standard, the findings emphasize that limited layer damping is a realistic and efficient solution for vibration manage in lightweight structures. The outcomes obtained may be used as a reference for designing damping structures in robot and other mechanical applications where vibration discount is critical.

## 6. CONCLUSION

The vibration characteristics of a robotic arm had been analyzed the usage of finite element techniques. The utility of limited layer damping notably reduces vibration amplitude beneath harmonic loading conditions. many of the materials studied, Butyl Rubber gives the best damping performance. growing thickness improves damping however does not provide proportional development.

The examine confirms that material selection plays a more essential role than thickness in vibration control. The findings may be applied to improve the performance of light-weight mechanical systems.

The effects obtained from both modal and harmonic analyses offer a clear information of the dynamic behavior of the robotic arm and the effectiveness of damping techniques. The huge reduction in height deformation confirms that restricted layer damping is a reliable technique for controlling vibration in light-weight structures.



The comparative evaluation of different viscoelastic substances highlights the importance of choosing suitable material properties for achieving most beneficial performance. The superior performance of Butyl Rubber demonstrates its suitability for packages requiring high strength dissipation.

The study additionally shows that whilst thickness contributes to improved damping, its impact is limited beyond a positive range. This shows that growing material thickness by itself isn't always an efficient method, and careful selection of material traits is essential.

universal, the findings of this work may be used as a guideline for designing damping structures in robotic palms and similar mechanical structures. The approach followed on this examine may be extended to different programs where vibration control is important for enhancing accuracy, stability, and structural reliability.

## 7. FUTURE WORK

Further investigations can also consider the effect of different boundary situations and loading situations to evaluate the robustness of the damping method underneath actual working conditions. The have an effect on of varying excitation forces and frequencies can offer a deeper understanding of device conduct.

advanced studies may also explore using hybrid damping strategies via combining one-of-a-kind viscoelastic substances to achieve stepped forward overall performance. Optimization strategies can also be implemented to determine the only combination of material type, thickness, and placement for optimum vibration discount.

in addition, the impact of environmental elements including temperature, humidity, and lengthy-time period cloth degradation can be analyzed to evaluate the durability and reliability of damping substances in sensible programs. The combination of experimental validation with numerical simulation will help in enhancing the accuracy of consequences and making sure real- world applicability. Such studies will make a contribution to the development of greater efficient and dependable vibration control structures for robotic and different mechanical structures.

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