

Designing Robotic Systems for Shock, Vibration, and Impact

How Engineers Improve Reliability by Managing Energy, Not Just Strength



— INTRODUCTION

Modern robotic and automation systems are designed for speed, precision, and repeatability. As throughput increases and cycle times shrink, systems are exposed to higher dynamic forces than ever before. Acceleration, deceleration, hard stops, and incidental impacts are no longer edge cases — they are part of normal operation.

Despite this reality, shock and vibration are often underdesigned failure modes. Components may meet static load requirements yet fail prematurely once exposed to real-world dynamic conditions. Over time, unmanaged energy leads to fatigue, misalignment, electronic interference, and reduced system life.

This white paper examines where shock and vibration originate in robotic systems, why rigid designs often fail over time, and how engineers can design compliant solutions that improve long-term reliability without sacrificing performance.

Where Shock and Vibration Originate in Robotic Systems

Shock and vibration are inherent in robotics. Even well-designed systems generate dynamic forces that propagate through structures and components.

Common sources include:

Rapid acceleration and deceleration	High-speed motion profiles introduce inertial loads that repeat thousands or millions of times over a system's life.
Start-stop and indexing motion	Frequent changes in direction create cyclical loading that contributes to fatigue.
Hard stops and end-of-travel events	When motion is arrested abruptly, energy must go somewhere — often into the structure.
Incidental contact or collisions	Interaction with parts, fixtures, or neighboring systems introduces unpredictable shock loads.
Resonance and vibration amplification	Certain operating frequencies can excite structural resonance, amplifying vibration beyond what was anticipated in design.

While these forces may seem minor individually, their cumulative effect can significantly degrade system performance over time.



Why Rigid Designs Fail Over Time

A common response to shock and vibration is to increase stiffness or strength. While this may prevent immediate deformation, it often introduces new problems.

Rigid materials such as metals and hard plastics transmit energy rather than absorb it. As a result, shock and vibration are carried directly into mounts, fasteners, bearings, sensors, and electronics.

Common failure modes associated with overly rigid designs include:

- Fatigue cracking at mounting points
- Increased noise and structure-borne vibration
- Accelerated wear of adjacent components
- Loosened fasteners and hardware
- Sensor drift or electronic interference

In many cases, failures occur away from the original source of shock, making root cause analysis difficult. The system may appear “strong enough,” yet reliability continues to suffer.

The key issue is not insufficient strength — it is poor energy management.

Strength vs. Energy Management

Designing for dynamic systems requires a different mindset than designing for static loads.

STRENGTH-FOCUSED	ENERGY-MANAGED
Strength-focused designs resist force but pass energy through the system.	Energy-managed designs absorb, dampen, and dissipate energy before it propagates.

In robotics, managing energy is often more important than maximizing stiffness. Controlled compliance can reduce peak forces, limit vibration transmission, and protect sensitive components without compromising accuracy or throughput.

This is where compliant materials and structures play a critical role.

Designing for Shock and Vibration Control

Effective shock and vibration control is achieved by placing compliance where energy enters the system, not as an afterthought.

Engineers commonly introduce compliant solutions in the following areas:

MOUNTING INTERFACES

Interfaces between motors, actuators, electronics, and frames are prime locations for vibration transfer. Introducing compliant materials at these interfaces reduces transmitted energy and protects downstream components.

IMPACT ZONES

Hard stops, travel limits, and collision points benefit from materials that absorb energy progressively rather than stopping motion abruptly.

PROTECTIVE STRUCTURES

Enclosures, guards, and housings can be designed to absorb shock and dampen vibration instead of amplifying it.

Role of Urethane Materials in Robotics

Urethanes offer a unique balance of durability and compliance that makes them well suited for dynamic robotic environments.

SOLID URETHANES

Solid cast urethanes can be engineered to provide controlled stiffness while absorbing vibration and shock. They are commonly used in:

- Protective structures and housings
- Mounting interfaces
- High-load components exposed to dynamic forces

Material properties can be tailored to balance wear resistance, stiffness, and damping behavior.

URETHANE FOAMS

Urethane foams are designed specifically for energy absorption. Through controlled compression, they slow impacts and reduce peak forces.

Foam solutions are commonly used for:

- Bumpers and end stops
- Cushioning at hard interfaces
- Protection of sensitive robotic components

Proper foam selection allows engineers to absorb energy without excessive rebound or permanent deformation.

CASE SNAPSHOTS

Cleanroom Robotics Wheel Development

A major automation OEM required urethane wheels capable of meeting ISO cleanroom requirements while maintaining durability and tight tolerances. Through multiple rounds of rapid prototyping and engineering collaboration, a custom conductive urethane formulation and controlled manufacturing process were developed. The final solution met cleanliness requirements, delivered extended wear life, and supported a critical product launch timeline.

Impact Protection Using Urethane Foam

In a high-speed automation system, rigid stops caused repeated component damage from incidental impacts. Urethane foam bumpers were introduced to absorb impact energy through controlled compression. The solution reduced peak loads, minimized damage, and improved long-term system stability without affecting cycle time.



Key Takeaways

- 01 Shock and vibration are unavoidable in robotic systems — unmanaged energy is not.
- 02 Rigid designs transmit energy and often accelerate fatigue failures.
- 03 Designing for energy absorption improves reliability without sacrificing performance.
- 04 Compliant materials such as solid urethanes and urethane foams play a critical role in managing dynamic forces.
- 05 Addressing shock and vibration early in the design process prevents costly downstream redesigns.

Conclusion

As robotic systems continue to increase in speed and complexity, managing shock and vibration becomes essential to long-term performance and reliability. Designing for strength alone is no longer sufficient.

By identifying where dynamic forces originate and incorporating compliant materials at critical interfaces, engineers can protect components, reduce noise and fatigue, and extend system life.

If shock, vibration, or impact is limiting the performance of a robotic or automation system, engaging material and manufacturing expertise early can make the difference between repeated failures and a robust, scalable solution.



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