Downhole Isolators

Innovative Solutions in Mitigating Shock and Vibration
White Paper

Parker LORD

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Downhole Isolators

Innovative Solutions in Mitigating Shock and Vibration

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As an engineer in our Erie, PA facility, Zack designs and develops elastomeric solutions that mitigate shock and vibration in downhole oil and gas applications. His innovative ideas and reputation for first-class engineering support have led to the development of isolators that increase reliability and decrease non-productive time for customers.

Abstract

Mitigating shock and vibration is an ever-growing challenge in the directional drilling industry, particularly when protecting the sensitive electronics within the Measurement While Drilling (MWD) tool string. Since no two wells, flow rates, or bottom hole assemblies (BHA) are the same, providing a solution that can passively tune to the environment is key. Numerous companies have designed, built and trialed isolator after isolator to try to accommodate the increasing demands of the oilfield. Most of these isolators rely on a steel spring system or viscous damping by displacing fluid through an orifice. Some of the shortfalls of these designs are becoming apparent as a broader range isolator is needed to counteract the increased levels of shock and vibration. These traditional style isolators provide a linear spring rate, so as conditions change, the spring rate cannot provide adequate performance for the environment. Parker LORD has nearly a century of proven aerospace and industrial vibration and shock expertise and is making a disruptive impact by providing passive elastomeric isolators. Passively tuned isolators have a nonlinear response, which provides broad frequency isolation that can be used in a variety of applications. These isolators are designed as fully mechanical solutions to make repair and maintenance simple by removing the need for fluid fill.

Introduction

Elastomer technology is used in various industrial and aerospace markets. Parker LORD brings experience and new disruptive technology into the oil and gas market. Combining Parker LORD's rubber-to-metal bonding with proprietary elastomer technology provides performance and reliability that is not attained by traditional isolators. Elastomer provides compliance and introduces damping into the application. By utilizing nonlinear elastomer properties in a unique patented design, performance is passively tuned to input or loading. For example, the isolator will respond with a lower spring rate at lower input levels, which allows for greater displacement. Combining damping with larger displacement allows for more energy to be absorbed and dissipated to protect the isolated mass. Conversely, under a large input, the spring rate asymptotically increases until the material bulk loads (cannot displace any further due to incompressibility and lack of free volume). Under bulk loading, the isolator creates a soft snubbing action and prevents metal-on-metal contact.

Elastomeric isolators are an effective solution to minimize transmissibility of a shock input to an isolated mass. Shock mitigation is directly related to the elongation of the shock pulse duration. Figure 1 shows the transmission between input shock to output acceleration into the isolated mass. For example, the longer a pulse width can be extended, the more energy that can be dissipated before transferring the remaining energy to the isolated mass. The increase in time allows the elastomer damping to mitigate the peak shock levels. A rigid, non-isolated mass will typically have a shock transmissibility factor greater than 1 if the natural frequency approaches the shock frequency. Figure 2 shows a shock transmissibility factor of 1.4 under a half sine shock input with a 1:1 natural frequency to shock frequency ratio. Since a rigid system has negligible damping, this amplified shock input is transmitted directly to sensitive system components. For example, a shock input of 100G's into a rigid system can amplify to 140G's or greater causing unexpected damage.

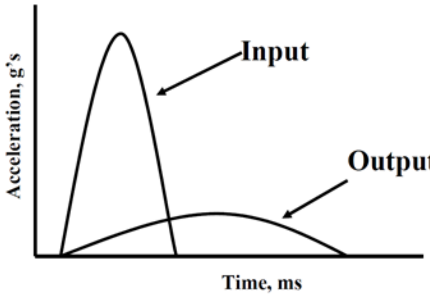

Figure 1: Shock Transmission Plot

Dynamic Vibration and Shock Modes

Parker LORD designs isolators using elastomer technology to mitigate the broad spectrum of shock and vibration during drilling and other high shock operations. There are three significant input modes that must be mitigated to protect MWD components from shock

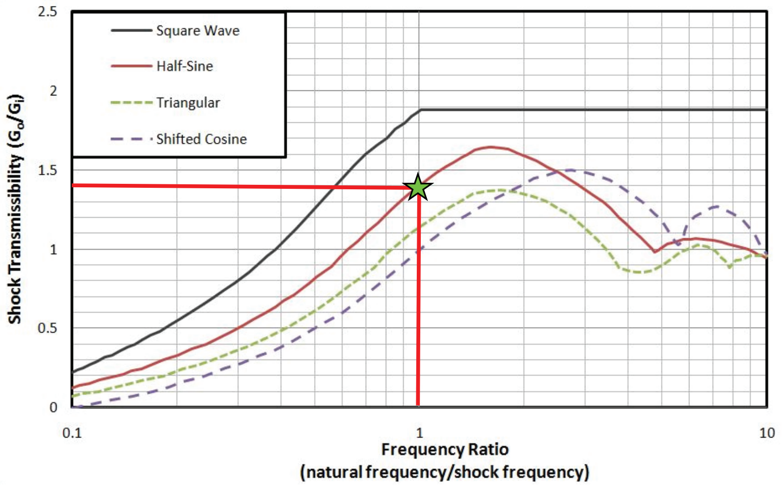

Figure 2: Shock Transmissibility vs. Frequency Ratio

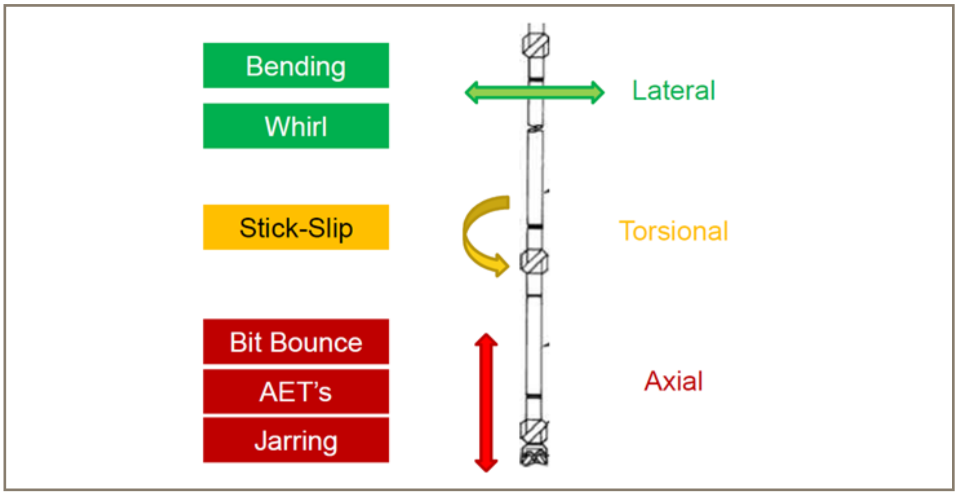

Figure 3: Downhole Dynamic Vibration and Shock Modes

and vibration. These dynamic modes are in the axial, lateral and torsional directions. Figure 3 represents the three modes of dynamic inputs into the system.

Axial Inputs

The first mode that is typically most damaging is an axial input. Axial shock events can exceed 200Gs in extreme shock events. Axial shock can result from bit bounce, axial excitation tools and jarring. Parker LORD has mitigated shock events upwards of 90% with the use of the Axial Isolator and SoftShoe Isolator patented technology. Axial shock events are mitigated by providing compliance in the axial direction. The isolators are designed to compress over an input duration and allow energy to be removed from the system through damping.

The LORD® Axial Isolator is a tool string level isolator that is installed directly between the pulser driver and lower end of the MWD system (Figure 4). It mitigates shock through a series of metal and rubber bonded elements. The isolator is designed to cover a broad spectrum of inputs, and under severe loading it will bulk load and asymptotically stiffen to prevent overloading the isolator. Bulk loading is achieved by compressing free volume of the elastomer until there is no free volume left in the isolator body. Since

Figure 4: LORD® Axial Isolator

elastomer is nearly incompressible, the spring rate asymptotically increases and protects against metal-to-metal contact. The Axial Isolator provides industry leading axial shock protection due to its design principles. Figure 5 and Figure 6 show a comparison of shock data between trials without an Axial Isolator and with an Axial Isolator. Table 1 shows the tabulated shock counts of the trial runs in Figure 5. During field testing, shock mitigation reached levels upwards of 90%.

Table 1: Shock Count

Magnitude	*Without* LORD Axial Isolator	*With* LORD Axial Isolator
30 - 40 g	1495	2
40 - 50 g	70	0

The LORD® SoftShoe Isolator also provides MWD tool string level protection. The SoftShoe provides similar axial shock protection to the Axial Isolator. The SoftShoe Isolator operates using the same principles as the Axial Isolator. It uses similar rubber-to-metal bonded stacks within the isolator to provide compliance and damping; however, the SoftShoe Isolator is located in the Universal Bottom Hole Orientation Sub (UBHO) and does not extend the length of the tool string. Relatively low operating costs and high flow capabilities are some of the benefits that the SoftShoe Isolator provides. The SoftShoe Isolator installs on the bottom of the muleshoe landing sleeve within the UBHO (Figure 7). Typically, a SoftShoe Isolator provides upwards of 60% axial shock mitigation.

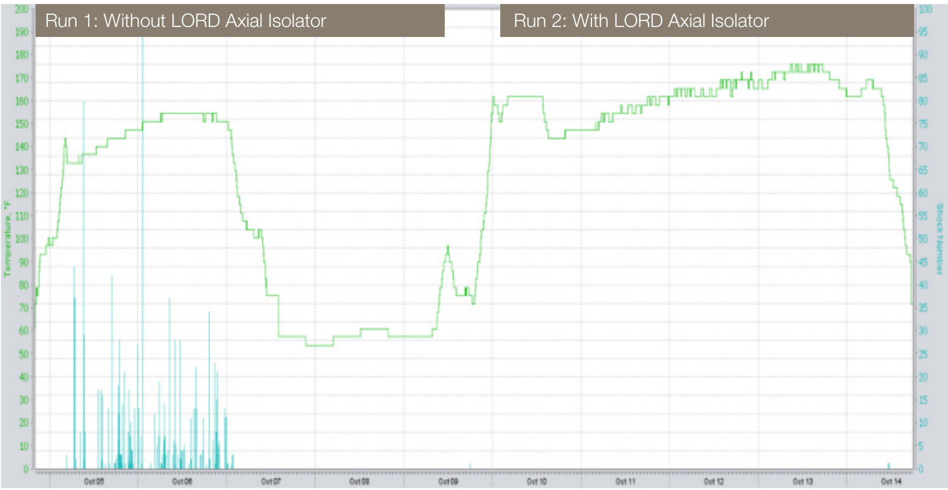

Figure 5: Shock Count Number Comparison

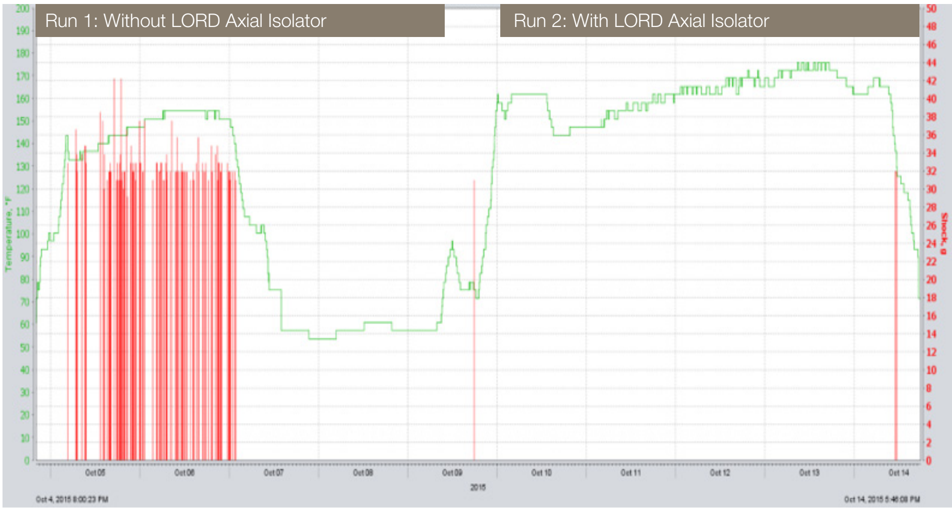

Figure 6: Shock Magnitude Comparison

Figure 7: LORD® SoftShoe Isolator installed in Universal Bottom Hole Orientation (UBHO) Sub

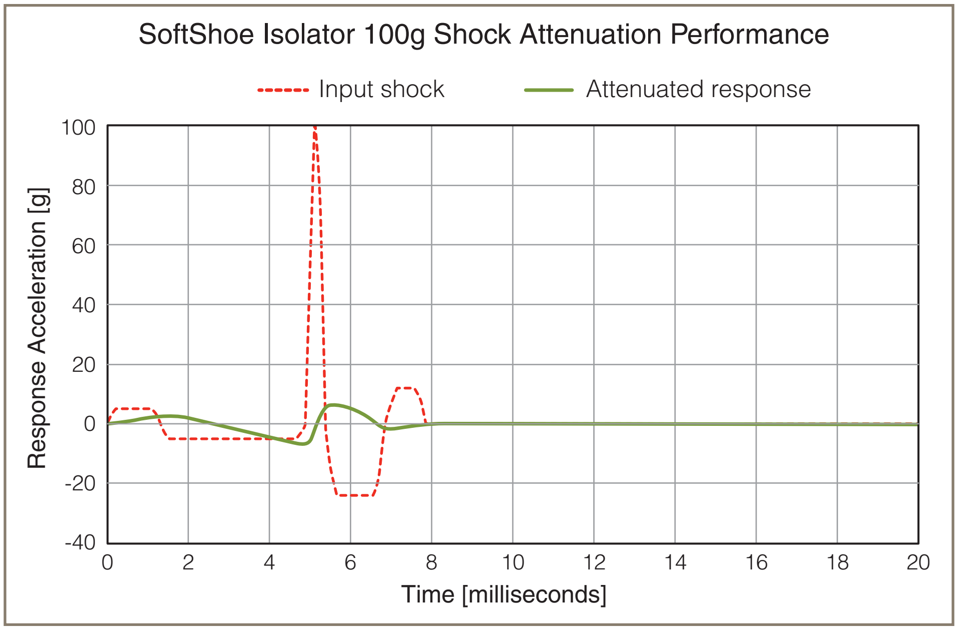

Figure 8: Half-sine 100g Input with 0.5 millisecond Pulse Width

Figure 9: LORD® Snubber

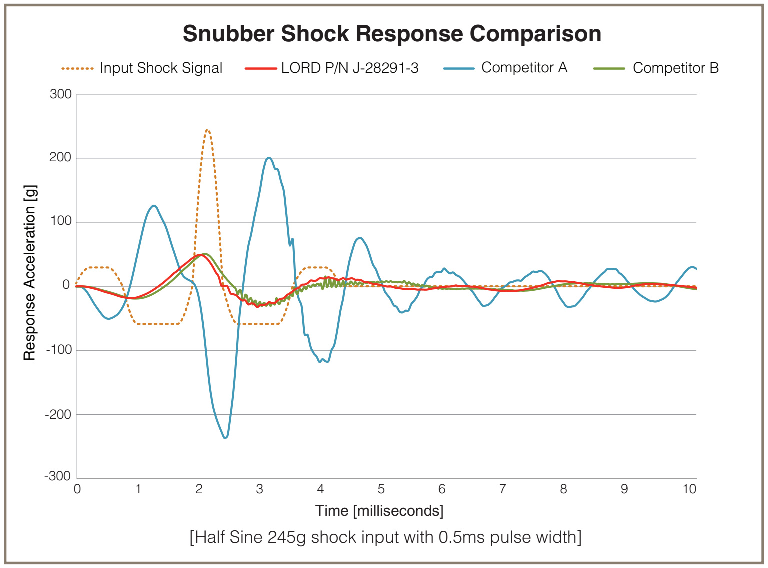

Figure 10: Snubber Performance Testing

Table 2: Lab Test Results with a 40g Input

Input [g]*	Output [g]	Duration [ms]	Shock Mitigation
40	0.791	0.5	96%
40	1.712	1	93%
40	1.900	2	93%
40	2.405	3	91%

Figure 8 shows the theoretical results of a 100G 0.5 ms half sine shock input. Actual test data is shown in Table 2. Testing was limited to 40Gs due to equipment limitations.

The LORD® Snubber shown in Figure 9 is a critical isolator to ensure full protection from shock and vibration. The snubber mitigates shock and vibration at the MWD module level. The snubber is attached directly to sensitive electronics, modules and battery packs within the MWD tool string. LORD Snubbers are designed to mitigate axial, lateral and torsional shock and vibration. By using proven elastomer technology and design expertise from multiple industries, LORD Snubbers outperform competing snubbers often on a factor of 100 times. This design combines fatigue life benefits of a fully bonded elastomer section while matching the performance of a soft insert-style snubber. Figure 10 shows head-to-head comparison of the LORD Snubber versus two competitor snubbers. Table 3 shows extrapolated endurance testing of the head to head test.

Table 3: Extrapolated Snubber Life

Snubber	Extrapolated Hours Downhole	Time to Failure	Failure Mode	Failure Description
LORD Snubber	>1800 hours	>40 hours	N/A	40 hours completed without failure
Competitor A: Fully Bonded	22.5 hours	30 minutes	Chassis	Cap screw failure
Competitor B: Insert Style	<3 hours	4 minutes	Snubber	Catastrophic elastomer insert failure

Input: 0.81 g^2/Hz; Test Mass: 4.75 lb

Figure 11: LORD® Lateral Isolator installed onto an Axial Isolator

Lateral Shock and Vibration

Once axial shock was mitigated successfully, lateral shock and vibration remained and became the primary cause of in tool damage. Lateral shock and vibration is becoming an increasing concern in directional drilling due to longer laterals, aggressive drilling and more challenging formations. Lateral shock can reach upwards of 120Gs and cause significant damage to sensitive electronics. In addition to field data, SPE Paper 127413 written in 2010 referenced that MWD component failure was most highly correlated to lateral accelerations. This paper was focused on collar-based tools, however the conclusions are still valid, if not more critical to probe style tools.

The LORD® Lateral Isolator and centralizer fins were designed to run in a probe style MWD tool string to protect against lateral shock and vibration. The Lateral Isolator decouples the lower end of the tool string from the remainder of the tool string. This provides a designated inflection point that adds damping and compliance into a rigid system. The Lateral Isolator uses a pair of highly engineered elastomer elements that provide compliance in the system. The Lateral Isolator is paired with an Axial Isolator that has fins installed on the body, also referred to as a Centralized Axial Isolator, shown in Figure 11. These fins are designed to mitigate lateral shock and vibration through proprietary elastomer and design, providing tuned performance to the drilling environment. Both the Lateral Isolator and fin geometry are patent pending and provide shock mitigation against lateral inputs.

Figures 13, 14 and 15 represent a series of downhole trials comparing different configurations and levels of isolation. The first setup is with no isolators, a rigidly mounted system. The second setup is with a non-finned version of the Axial Isolator shock tool. The third setup includes the Centralized Axial Isolator. The fourth setup utilizes a Lateral Isolator installed in series directly above the Centralized Axial Isolator.

Figure 12: Downhole Trial MWD Tool String Configuration

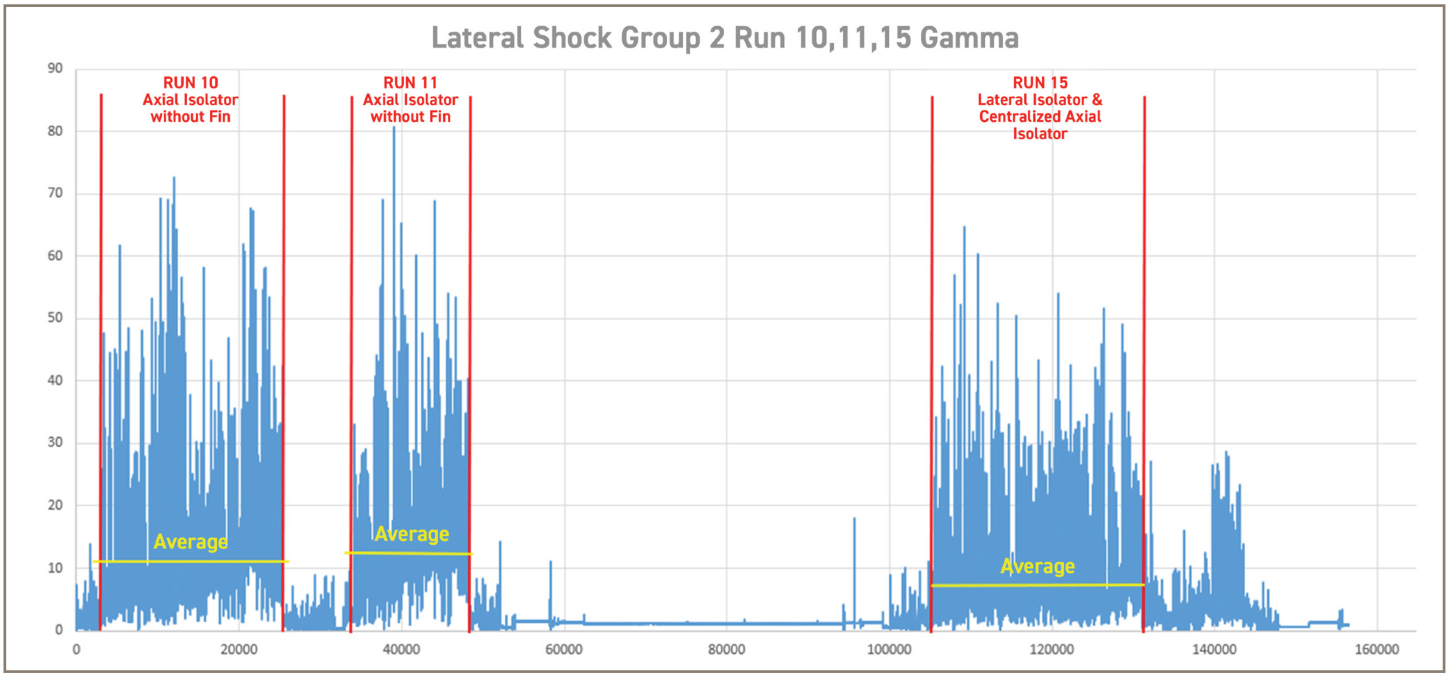

Figure 13. Lateral Shock Run 10, 11, 15 Gamma Module

The Lateral Isolator was run in series with an Axial Isolator as shown in Figure 11.

The Lateral Isolator was installed to the upstream connection of the Axial Isolator, extending the mud column between the lower end and pulser driver.

This series of data was run with the following setup of the gamma, pulser, and directional modules shown in Figure 12. Data was collected from the Directional, Gamma, and Pulser Module.

The following run data was acquired in a lateral segment in comparable run conditions. Results showed favorable shock mitigation with the greatest mitigation being closest to the lateral isolator. The isolator provided the highest shock mitigation near the pulser and gamma modules. This is likely due to the proximity of the lateral isolator to these components. Performance was also best due to greater exposure to high (>30 g) shock events typically seen towards the lower end of the tool string. The lateral isolator performs incrementally better as shock inputs increase.

Data was compiled using the start and end of the drilling segment as shown in Figure 13, which represents an example of Runs 10, 11 and 15 from the gamma module. Runs 10 and 11 were with a standard Axial Isolator, while Run 15 included a Centralized Axial Isolator and Lateral Isolator.

Figure 14 and Figure 15 show the comparison between runs with no isolation tool and runs with a Centralized Axial Isolator. The runs with the Centralized Axial Isolator reduced average shock significantly but did not remove all the high input peaks. Mitigating these peaks is the primary focus of the Lateral Isolator.

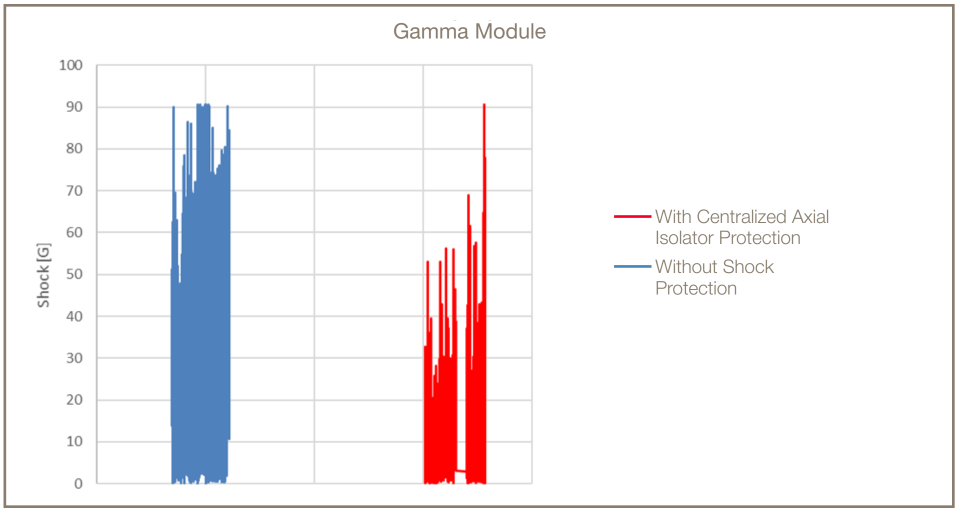

Figure 14. Lateral Shock — Gamma Module

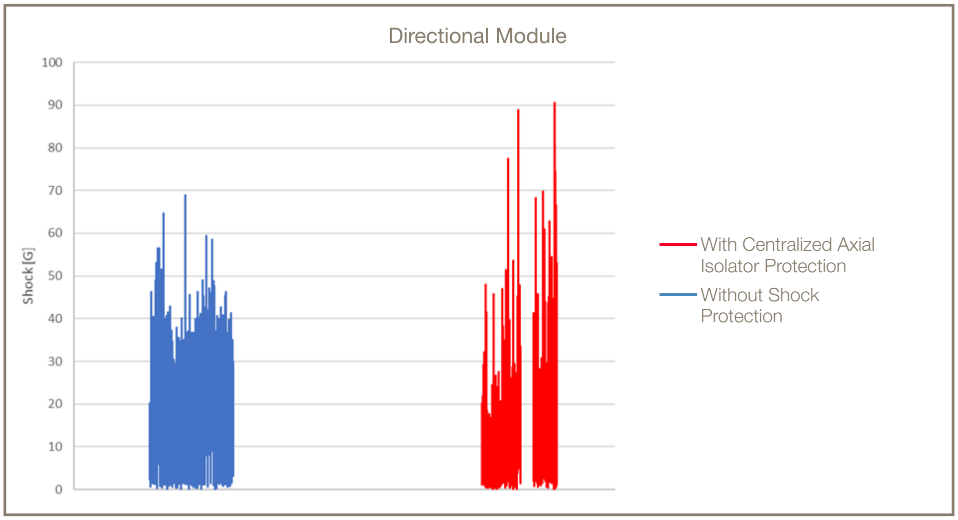

Figure 15. Lateral Shock — Directional Module

Table 4 summarizes run data pulled from the pulser module. Shock mitigated compares a setup with an Axial Isolator without fins to a setup with a Centralized Axial Isolator in series with a Lateral Isolator. The data showed an average shock reduction of approximately 30%; however, the benefit is seen in the normalized data for shock counts per hour. Results show approximately an 88% reduction of shock counts greater than 30Gs. The results also confirmed that the benefits are likely to be more noticed at higher shock levels. Shock mitigated is calculated by comparing the two categories of runs.

Table 4: Pulser Module Average Lateral Shock

Lateral Shock - Pulser Module				
Setup	**Average Shock [G]**	**Average >30 G Shock/Hr**	**Average >20 G Shock/Hr**	**Average >10 G Shock/Hr**
Axial Isolator	10.0	18.2	82.1	281.9
Centeralized Axial Isolator, Lateral Isolator	7.1	2.2	20.5	151.0
Shock Mitigated	29.7%	87.7%	75.1%	46.4%

Table 5: Gamma Module Average Lateral Shock

Lateral Shock - Gamma Module				
Setup	**Average Shock [G]**	**Average >30 G Shock/Hr**	**Average >20 G Shock/Hr**	**Average >10 G Shock/Hr**
No Shock Isolator	31.0	329.3	537.7	635.3
Axial Isolator	15.0	84.9	179.4	422.8
Centeralized Axial Isolator	8.5	4.7	33.4	213.7
Centeralized Axial Isolator, Lateral Isolator	10.3	20.4	76.8	295.7
Shock Mitigated	66.7%	93.8%	85.7%	53.5%

Table 6: Directional Module Average Lateral Shock

Lateral Shock - Directional Module				
Setup	**Average Shock [G]**	**Average >30 G Shock/Hr**	**Average >20 G Shock/Hr**	**Average >10 G Shock/Hr**
No Shock Isolator	15.4	15.9	172.0	575.0
Axial Isolator	9.5	2.9	30.4	294.1
Centeralized Axial Isolator	7.7	9.5	51.7	273.1
Centeralized Axial Isolator, Lateral with Fins	8.6	2.3	25.4	237.8
Shock Mitigated	44.3%	85.4%	85.2%	58.6%

Table 5 summarizes run data pulled from the gamma module. The data showed an average shock reduction of approximately 67% when comparing a Centralized Axial Isolator / Lateral Isolator configuration to the unisolated tool string. Like the pulser module, the benefits are seen in shock counts per hour. Results show approximately a 94% reduction of shock counts greater than 30Gs when comparing a Centralized Axial Isolator / Lateral Isolator configuration to the unisolated tool string. The results also confirmed that the benefits are greater at higher shock levels.

Table 6 summarizes run data pulled from the directional module. The data showed an average shock reduction of approximately 44%. Results show approximately an 85% reduction of shock counts greater than 30Gs when comparing a Centralized Axial Isolator / Lateral Isolator configuration to the unisolated tool string. The shock mitigation is less on the directional module due to the lower overall shock inputs at this location of the tool string.

Overall, the goal of reducing lateral shock and vibration was successful. The isolators performed as expected and showed a direct correlation of reducing lateral shock and vibration when a Lateral Isolator and Centralized Axial Isolator were paired together downhole. The Centralized Axial Isolator provides a stabilized lower end while the Lateral Isolator decouples the lower end shock from the remainder of the tool string. Tool string reliability will also be significantly increased by running a Centralized Axial Isolator and Lateral Isolator due to the increased stabilization and decreased bending stresses. Pressure barrel cracking or fractures caused by bending are minimized by the inflection point created by the Lateral Isolator. The Centralized Axial Isolator lowers the average shock and vibration and mitigates some of the peak inputs; however, since the lower end is not fully decoupled in comparison to running a Lateral Isolator, higher shock inputs can still occur. The fins and isolator are considered a multi-stage isolation system. Stage 1 includes running fins on the Axial Isolator and Lateral Isolator to lower the average shock and vibration levels. Stage 2 introduces a damped inflection point into the system by adding the Lateral Isolator to the Centralized Axial Isolator which provides the highest level of protection.

Summary and Conclusion

As drilling parameters push to new limits, shock and vibration are an increasing challenge. Cost, time, depth and challenging formations are driving innovative solutions such as isolators and shock tools. This paper summarizes the history and technology of Parker LORD isolators from the original Axial Isolator and Snubber, to the SoftShoe Isolator, to finally the Lateral Isolator and Centralizer Fins. Parker LORD oil and gas technology leverages a combination of specialized knowledge of dynamics, elastomer formulation and isolator design to provide solutions that can mitigate upwards of 90 percent of shock and vibration inputs. The result is reduced downtime, increased productivity and industry-leading reliability. With a complete engineered isolator package acting as springs in series, the customer can expect the best shock and vibration mitigation and tool string protection.

OD LL6025 12/20 Rev.0

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