2018 NDIA GROUND VEHICLE SYSTEMS ENGINEERING AND TECHNOLOGY SYMPOSIUM
POWER & MOBILITY (P&M) TECHNICAL SESSION
AUGUST 7-9, 2018 - NOVI, MICHIGAN

DEVELOPMENT OF AN EFFICIENT, LEAK PROOF PLENUM SEAL FOR THE M1 ABRAMS ENGINE INLET

Steve Tarnowski
Steve Pennala
Great Lakes Sound & Vibration Inc.
Houghton, MI

Mary Goryca
U.S. Army TARDEC
Warren, MI

Kevin Kauth
KBRwyle
Warren, MI

ABSTRACT

The M1 Abrams will be the primary heavy combat vehicle for the US military for years to come. Improvements to the M1 that increase reliability and reduce maintenance will have a multi-year payback. The M1 engine intake plenum seal couples the air intake plenum to the turbine inlet, and has opportunities for improvement to reduce leakage and intake of FOD (foreign object debris) into the engine, which causes damage and premature wear of expensive components.

INTRODUCTION

Great Lakes Sound and Vibration Inc. (GLSV) has developed a novel, improved plenum seal design for the M1 engine intake under an Army Phase-II SBIR program.

The M1 Abrams is powered by the AGT 1500 gas turbine engine. As the power pack is installed, the plenum seal couples the air intake plenum to the turbine inlet and is engaged by a press fit during installation. Unfortunately, due to dimensional variations between vehicles and difficulties in verifying proper installation the seal does not consistently perform as intended, resulting in leak paths for sand and water to enter the turbine. This intrusion leads to premature wear of expensive components, ultimately resulting in a costly and time consuming overhaul or replacement of the turbine. A cost benefit analysis can show that the US Army could save millions of dollars per year on turbine overhauls by implementing an improved plenum seal.

Figure 1 shows the current production plenum seal installed on the FOD screen assembly at the engine inlet. Not shown (to the left of the FOD screen) is the plenum box opening that engages with the seal when the engine is installed.

Figure 1: Plenum seal and FOD screen

DISTRIBUTION STATEMENT A. Approved for public release; distribution unlimited.

SEAL DESIGN CHALLENGES

There were several challenges to overcome in developing a high performing, leak proof plenum seal. Perhaps the biggest challenge is the configuration of the sealing interfaces and the air gap that needs to be filled by the plenum seal. The plenum seal fills the gap between the air intake plenum box and the turbine inlet. The outlet on the plenum and the inlet of the turbine are not concentric and both parts contain a large positional tolerance. Thirteen M1 Abrams hulls were measured at the Anniston Army Depot assembly and disassembly lines to determine the approximate alignment variation to expect. The measurements were compared to the tolerance stack-up that is based on OEM hull drawings to verify the worst case alignments that might be seen in the field. Combined with relative motion due to shock and vibration, this makes the sealing envelope and interfaces very complex.

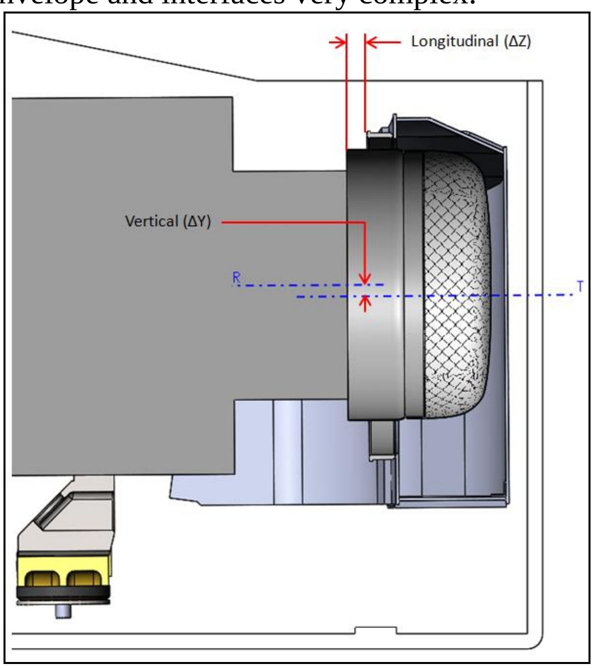

Figure 2: Side view of power pack and plenum box.

Another challenge to implementing a new seal on the M1 Abrams is the manner in which the seal must be seated in its final position. The seal must be fixed to the turbine inlet before the power pack is installed into the hull. As the power pack is lowered into its final position, the seal must seat itself on the plenum ring. The plenum ring protrudes from the plenum box and provides a cylindrical surface for the seal to encapsulate, creating an interference fit with enough pressure to create the airtight seal. There is not enough room around the plenum seal for a mechanic to manually ensure the seal goes onto the plenum ring during power pack installation. Even after the power pack is installed it is difficult to determine if the seal is properly installed. The mechanic must inspect the seal from the top side and then crawl under the vehicle, remove the inspection port cover, and inspect the bottom half of the seal interface. If the seal did not seat properly the pack must be pulled and reinstalled until the seal is properly seated. The third major challenge is the operating environment. The seal must withstand a temperature range of -60 to 300° F and account for thermal expansion of the power pack. Also, the plenum seal is attached to the engine so it must be able to meet certain functional vibration requirements. Per the AGT 1500 power pack requirements, the engine shall be capable of meeting its performance and functional requirements when exposed to sinusoidal vibration in all axes of the magnitudes and frequencies:

a) Freq = 5 to 25 Hz, Amplitude = +/- 1g
b) Freq = 25 to 51 Hz, Amplitude = 0.030 inch D.A.
c) Freq = 51 to 500 Hz, Amplitude = +/- 4g

The seal must also be able to withstand an internal vacuum pressure up to 100 IWG without permanent, physical damage. It must be able to function properly under a constant internal vacuum up to 50 IWG. These operating conditions really limit the choices for a suitable material. HNBR and FVMQ fluorosilicone rubber were the two materials chosen to be evaluated for the new plenum seal. The current production plenum seal uses FVMQ.

DISTRIBUTION STATEMENT A. Approved for public release; distribution unlimited.

DESIGN METHODOLOGY/APPROACH

GLSV took a systematic engineering approach to define the design requirements of the new seal and to develop and prototype a new concept design.

One of the greatest challenges to developing a high performance seal is being able to design for the large amount of dimensional variations from vehicle to vehicle. These variations are inherent in the allowable tolerances in the vehicle hull and engine compartment, interfaces, mounting points for the engine and plenum box, and the engine itself.

GLSV developed a plan to derive a comprehensive misalignment specification to incorporate in the seal design. The misalignment tolerance was developed using a combination of the vehicle measurements and tolerance stack-ups based on the vehicle drawings.

GLSV conducted a vehicle measurement survey of 13 different M1 vehicle hulls at the Anniston Army Depot, and also several power packs (engine + transmission). A portable, articulated, CMM arm was used to scan the engine compartment and vehicle hull features. An optical tracking system was used to scan the relevant features and components of each power pack.

The scanned geometry was used to create CAD assembly models to include the hull interfaces and features, the air intake plenum box, and the power pack. GLSV created CAD models of all 13 measured vehicle hulls, which were used to create virtual models of the hull/power pack assemblies. The virtual models were used to measure the amount of misalignment between the plenum box and engine inlet.

GLSV also utilized a tolerance study based on actual vehicle drawings. The results of the hull tolerance study were combined with the vehicle measurements to define the required sealing envelope/specification that the seal would be designed to. Figure 3 shows the CAD model that was created for the misalignment study.

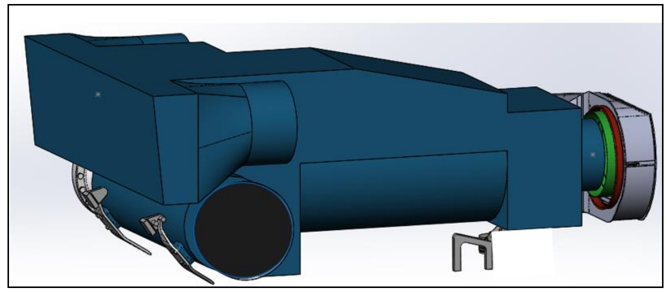

Figure 3: CAD assembly model of power pack and plenum box

GLSV also used the CAD assembly models to simulate the power pack motion trajectory during power pack installation into the vehicle. The Figure 4 shows a trace of the motion of the seal mounting interface during power pack assembly. This installation path was also considered in the seal design, in addition to the misalignment at the final installed position.

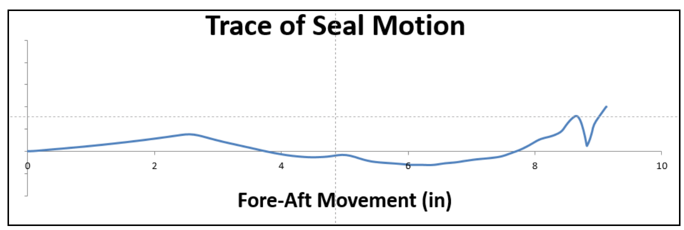

Figure 4: Trace of seal motion during power pack installation

In addition to the misalignment specification, GLSV's new seal design also considered extreme temperatures, fluid compatibility, thermal expansion, vibration, and flexural strength requirements.

With a well-defined space claim envelope and defined range of misalignment, GLSV developed several new seal design concepts. The initial design feasibility study considered several types or families of seal design. Material selection was

DISTRIBUTION STATEMENT A. Approved for public release; distribution unlimited.

considered for the environmental requirements, and manufacturing limitations were considered in the design also.

Detailed design and analysis included nonlinear finite element analysis (FEA) to evaluate sealing/leakage performance of the seal design. The analyses considered surface friction between the seal and metallic components, as well as simulating the motion path of the seal during power pack installation.

The analysis strategy was to perform 2-dimensional axisymmetric analysis to rapidly optimize and zero in on a favorable seal geometry. This allowed many design iterations to be evaluated in a short period of time. Once the design was refined to the point where the seal performed well in the 2D analysis, a more complete 3-dimensional finite element model was created to include the seal, FOD screen, plenum ring, and a partial model of the plenum box.

The 2D analysis results were used as initial conditions for the 3D analysis to evaluate the seal performance for various offset/misalignment conditions. The 3D analysis predicted structural stresses/strains in the seal, and contact pressures between the seal and interfaces.

The 3D analysis was set up with initial boundary conditions with the seal stretched over the FOD screen outer surface and over the plenum ring, with a radial clamp force applied. Then, combined radial and axial offsets were applied to the assembly.

Figure 5 shows a 3D finite element model of the seal assembly.

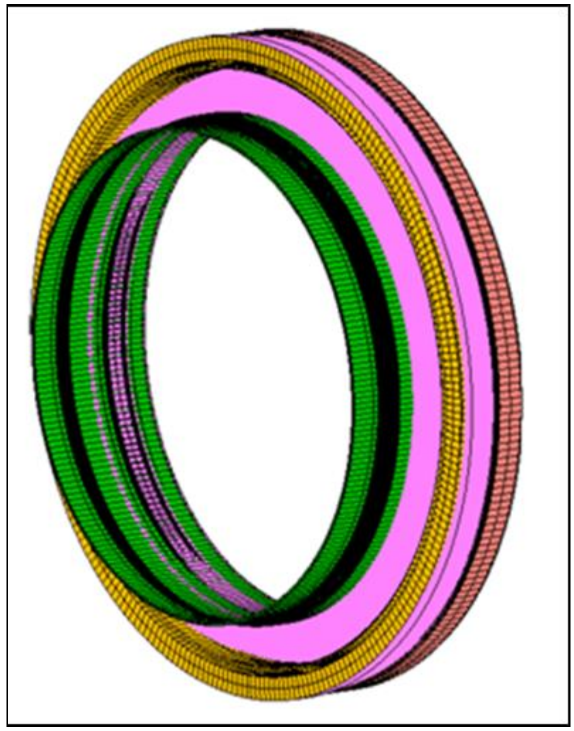

Figure 5: FE model of seal assembly

PROTOTYPE DEVELOPMENT

To support the development process several prototype seals were manufactured. The prototype process helped to validate the manufacturability of the design and provided test articles to verify durability and sealing performance in a laboratory environment. Several types of rubber seal concepts were being compared and needed to be evaluated for manufacturability. These included a molded over garter spring seal, bulb seal and solid lip seal. The molded over garter spring concept was not chosen for prototyping because of sealing performance limitations. It was also determined that a bulb seal would not meet the needs of this application, due to the limitations of the geometry that can be extruded and spliced together. Specifically, the size and cross-section required for this application makes it incapable of meeting the required bend radius for splicing, while also maintaining the orientation necessary for sealing.

DISTRIBUTION STATEMENT A. Approved for public release; distribution unlimited.

The extruded material has a linear orientation which must be altered during the splicing process so the ends of the extruded material can be bonded into a continuous ring. This results in residual stresses in the spliced ring in its free state. These stresses can alter the orientation of the extrusion profile and may cause the seal to buckle in some cases. The ideal concept for this approximate diameter and cross-section is a continuous molded seal, containing no residual stresses in its free state.

Multiple design concepts and several material combinations were evaluated and were deemed feasible with consideration for the single, continuous molded manufacturing process. The solid lip seal concept is able to be manufactured with a single cavity mold using a transfer molding process and the favorable, simulated performance results made it the first choice for prototyping and testing. Lip seals were produced with two different materials, 70 Durometer FVMQ and 70 Durometer HNBR.

FVMQ offers the best resistance to extreme temperatures and is very weather resistant. HNBR offers superior abrasion resistance and flexural strength. Both materials garnered respective designs that capitalize on their strengths and mitigate the negative impacts of their inherent weaknesses. The seal designed with FVMQ needed a feature that will reduce the abrasion due to vibration of the sealing surfaces. The current production seal uses FVMQ with plies of fabric impregnated in the sealing surface. This fabric provides the abrasion resistance that FVMQ lacks by itself. The drawback is that this does not allow the current seal to have a smooth sealing surface and may contribute to leakage. It is desirable to be able to use FVMQ without fabric reinforcements.

HNBR meets or exceeds all the material requirements except for operation at low temperature. One requirement is the plenum seal must be able to withstand temperatures of -60 degrees F and hold a vacuum for 20 seconds with the engine at idle. This low temperature case does not impose significant stresses on the seal and although the recommended low operating temperature of HNBR is in the -40 F range it is possible that a seal of this material can still meet the requirement.

Several molding trials were required to produce suitable seals for lab testing. These seals had minor, cosmetic blemishes but were fully functional for the intended usage. The tooling and transfer mold method were developed with production intent and will need only minor modifications to produce consistent, high quality parts in production. Both materials were able to lend themselves well to producing good prototype parts. The FVMQ and HNBR prototypes were both evaluated with extensive lab testing to support the down selection to the material of choice.

COMPARATIVE LAB TESTS

Following the prototype manufacturing, GLSV undertook a comprehensive lab testing effort to evaluate the seal performance. Comparative tests were also performed on the current production seal to gauge the relative performance. The lab tests included high temperature performance, leakage performance throughout the full range of misalignments, and combined environment testing to measure leakage performance during a flexural duty cycle at elevated temperatures.

Figure 6 shows GLSV's custom leak test fixture. The fixture includes a rigidly fixed plenum box with plenum ring that can be adjusted independently up/down and left/right to simulate various misalignment conditions. The surrogate FOD screen (shown here with plenum seal attached) is the movable portion of the fixture, and is guided through a precise path to simulate the actual trajectory/path that the engine follows during a power pack installation in the vehicle. Upper and lower hydraulic jacks are used to move the FOD screen through the guided trajectory and provide adequate force to engage the seal on the plenum ring. When the FOD screen/seal are in the final installed position with the seal engaged on the plenum ring, mechanical locks are engaged to hold it in place for vacuum leakage testing.

Figure 6: GLSV leak test fixture

Subsequent figures show additional lab test set ups. Figure 7 shows the environmental and vacuum leakage test setup. Figure 8 shows the flexural test setup, in which the seal was evaluated to withstand in-plane relative motion between the clamped surface of the seal on the FOD screen and the sealing interface on the plenum ring. During this test the plenum box was held fixed while the FOD screen was mounted to an electrodynamic shaker table to create the oscillatory relative motion.

Figure 7: GLSV environmental and leakage test setup

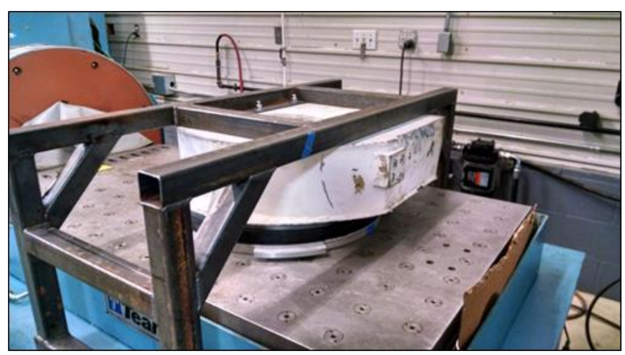

Figure 8: Flexural test setup

The initial lab tests of GLSV's new seal revealed several areas for improvement, which are being considered for the next round of design iterations and prototype development.

At the conclusion of the lab tests, GLSV's seal had met the static vacuum leakage requirements for almost the entire range of expected misalignment conditions. The revised production seal met the requirements for a much smaller envelope of misalignment; approximately half the effective envelope of the GLSV seal.

VEHICLE INSTALLATION TRIALS

Following the successful lab testing, GLSV conducted installation trials and fit verification tests of the prototype seals at the Anniston Army Depot. GLSV completed four install and removal tests on two different vehicles.

GLSV assisted ANAD personnel to install a prototype seal on a power pack, along with custom installation features to allow hands-free engagement and disengagement of the seal from the plenum box.

This functionality is very important, because the arrangement of the power pack inside the M1 engine compartment leaves very little space to apply the seal. It is not possible to reach completely around the turbine inlet once installed, hence the requirement for a hands-free operation. This means the seal must be secured to the power pack outside of the vehicle and the installation and mating with the plenum box is a blind process, and is nearly impossible to verify that the seal is seated correctly.

A completely new approach to the plenum seal design gives GLSV the opportunity to simplify the seal geometry to reduce manufacturing costs and installation time while also reducing the probability of installation errors.

GLSV mounted several remote cameras in the vehicle engine compartment to capture video for documentation of the installation and removal process. During every trial, it was observed that the plenum seal made proper engagement with the plenum ring all the way around the circumference. The lower video camera mounted on the hull floor was used to verify and document the seal engagement in the lower half of the plenum ring, which is normally not visible during power pack installation.

Similarly, GLSV's disengagement mechanism performed well, allowing the seal to automatically disengage from the plenum ring as the power pack was being removed from the vehicle.

GLSV received valuable feedback from ANAD factory personnel that assisted with the testing. The ANAD mechanics observed that the GLSV seal is easier to install on the FOD screen assembly, and the seal engaged more smoothly with the plenum ring during power pack installation. Another favorable characteristic of the GLSV seal is that it provides positive visual and audible feedback when it engages properly.

CONCLUSIONS

GLSV's new plenum seal prototype performed well in laboratory tests and vehicle installation trials. Vacuum leakage performance was significantly improved for a wide range of misalignment conditions, as compared to the current production seal. GLSV's seal also performed well at high temperatures, and while undergoing vibration that was representative of vehicle operating conditions. The GLSV seal also exhibited excellent durability during high-cycle flexural strength tests.

GLSV currently anticipates additional seal design improvements to be made during a Phase-III SBIR effort that will build on the previous work. GLSV is planning additional qualification and field tests, with the end goal of having a production level technical data package and production-intent tooling for the new plenum seal design.

DISTRIBUTION STATEMENT A. Approved for public release; distribution unlimited.