



## Hale Products, Inc. Service Bulletins

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Product Type Covered: Hale Pump

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Hurst Tool

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Lukas Tool

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Product Covered:

Hale Pumps

Problem Statement:

Driveline Design and Inspection - Best Practices

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### Body of the Bulletin

Hale OEM's around the world build custom fire apparatus and face many challenges. The driveline is critical to a long, reliable fire truck life cycle. This bulletin lists some of the best practices for the design and quality control of driveline installations. [Hale Service Bulletin SB66 \(Bulletin #957\)](#) provided some guidelines and issues. Although Hale SB66 is not obsolete, this bulletin expands, updates, and clarifies some of its points.

This document is intended to serve as a supplement to the information available in the industry and not a complete guide for the design and installation of drivelines and their components.

#### Driveline Design process – Best Practices

##### Checking system torque

Most applications do not experience issues with excessive system torque. However, checking for excessive torque is an important step of the process. Please refer to the latest revision of Hale Form F-72 for information concerning system torque checks to check possible issues relating to high torques. Form F-72 is part of the Hale Pump Recommendations List, published on [www.haleproducts.com/literature](http://www.haleproducts.com/literature), heading Articles.

##### Driveline Tube Size and Type

Driveline tube size and type should be selected by your driveline manufacturer based on your chassis specifications.

##### Driveline Lengths

Long drivelines can lead to components vibrating excessively or total driveline tube failure. As the driveline approaches ½ critical speeds, a vibration will develop which may not be felt but can shake the bolts loose from fixed components in the drive system. Chassis drive lines which approach the ½ critical speeds can experience catastrophic tube failure. Considering this, along with SAE design recommendations and other industry experience, Hale's maximum drive line length recommendations are based from 42% of critical speed as seen in Table 1.

When determining the length of the driveline sections always make sure to center your driveline sliders, look at suspension travel and vehicle loading to verify the sliders are not going to pull apart or bottom out. If a slider bottoms out severe damage could occur.

Table 1: SUGGESTED MAXIMUM DRIVE LINE LENGTH FOR SPLIT DRIVE LINE PTO OR TRANSMISSION PTO APPLICATIONS

Shaft RPM	Driveline tube size (diameter) in inches					
	2	2.5	3	3.5	4	4.5
2400	47	53	58	63	67	71
2500	46	52	56.5	61.5	65.5	69.5
2600	45	51	55	60	64	68
2700	44.5	50	54	59	63	66.5
2800	44	49	53	58	62	65
2900	43	48	52.5	57	61	64
3000	42	47	52	56	60	63
3100	41.5	46.5	51	55	59	62
3200	41	46	50	54	58	61
3300	40	45	49	53.5	57	60
3400	39	44	48	53	56	59
3500	38.5	43.5	47.5	52	55.5	58.5
3600	38	43	47	51	55	58
3700	37.5	42.5	46.5	50.5	54	57
3800	37	42	46	50	53	56
3900	36.5	41.5	45.5	49	52.5	55.5
4000	36	41	45	48	52	55

The numbers in the table above indicate the absolute maximum driveline length. Shaft RPM is calculated by determining the maximum speed that the driveline is capable of spinning. This is simply calculated by dividing the highest forward gear ratio into the engines govern speed. For example: A 2100 govern speed with a .75:1 top gear will produce 2800 driveline rpm's. Although the Allison 3000 and 4000 series transmissions have an available 6<sup>th</sup> gear, it is typically locked. This should be confirmed to ensure the section lengths are based off the correct driveline speeds.

#### **CRITICAL SPEED NOTE:**

The driveline lengths in table 1 are based on approximately 42% of critical speed. Operating a drive-shaft for prolonged periods of time at a steady speed which is about one half the shaft's calculated critical speed could lead to driveshaft failure or loosening of drive components. This is due to secondary couple forces in the Cardan u-joints that produce frequencies that oscillate at twice the shaft speed. With vibration isolating elastic components in the driveline mounting system, such as those found in center bearings or sometimes in pump compartment mountings, the effect critical speeds have on the system can be altered. The combination of vibration isolating components and critical speeds can produce instantaneous type failures with little warning to the vehicle operator. This failure type is quick and explosive in nature (See SAE Universal Joint and Driveshaft Design Manual AE-7 Chapter 10).

#### **Angles and Offsets**

The importance of a good driveline layout cannot be overstated. It is critical that the angles between components and the offset distances from a particular frame rail to each of those components are carefully considered.

A driveline scan program such as the one made by Dana/Spicer named "The Expert" (available at [www2.dana.com](http://www2.dana.com) under the "Torsional Analysis Program" link) should be used to verify your driveline dimensions. The verification process should be performed three times. One for the entire driveline system, one for the components from the transmission to the pump transfer case, and one for the components from the pump transfer case to the rear pinion. Making three scans will ensure that the system is properly designed for all operating conditions in pump and road modes and that the pump transfer case is properly aligned with both the transmission and the rear pinion.

The recommended limits of 300rad/s<sup>2</sup> for torsional and 1000rad/s<sup>2</sup> for inertial accelerations found in the program The Expert should be the absolute maximum limit for designing your system. The best designs stay below 50% of the recommended limits to account for the unavoidable variations that occur in production even at the best vehicle builders in the world.

Remember that split-shaft transfer cases found in most pumper units complicate the process since the shaft phasing on either side of the transfer case is not constant.

The following guidelines will help improve driveline life and performance:

- Run driveline scans throughout the vehicles suspension travel to check for exaggerated pinion angles at the extremes.
- The goal should always be to design the driveline so that there is a 1° difference between components. This is obviously not always feasible but the closer you get to this mark the better the driveline will perform and wear over time. This will also minimize your scan readings when using The Expert to analyze the system.
- Maintain shaft cancellation to and from the transfer case of the pump. Shaft cancellation is achieved by closely matching the angle of the driving component (i.e. truck transmission) and the angle of the driven component (i.e. pumps transfer case or rear pinion).
- Limit the suspension travel for chassis that have very short rear drivelines, from pump or center bearing to the rear axle, to prevent severe angles from occurring during the extremes of suspension actuation. This is especially important for tandem axle air ride suspensions where theory and evidence suggests that the suspension actuation accelerates quicker than a traditional spring suspension adding to the potential for extra forces from increased accelerations.
- Use a bolt loosening indicator such as F-900 "Torque Seal"<sup>1</sup> for easy inspection of driveline component fasteners.
- Make sure each driveline section is phased properly. Contact your driveline manufacturer for proper phasing in your vehicle.
- Looking down onto the vehicle in the plan view, layout the driveline as straight as possible. Maintaining equal distance between frame-rails will improve your scan results and lower vibration and decrease wear over time. Remember, any offset is part of the total driveline angle.

<sup>1</sup> F-900 "Torque Seal" available through Organic Products Company at <http://www.opcompany.com/index.html>

## **Driveline Manufacturing Processes – Best Practices**

### *Drive-shaft Balance*

An improperly balanced drive-shaft can cause very premature failure in a driveline system. Every OEM should know what the balancing requirements are and if the supplier meets those requirements. Help in understanding balancing requirements can be found in the SAE Universal Joint and Driveshaft Design Manual AE-7. The specific balancing allowances for a particular drive-shaft should be supplied by the driveline manufacturer; for example Dana/Spicer driveline installation guide J-3311-1 which specifies a maximum of 1.00 oz-in for each ten pounds of driveshaft weight divided proportionally at each end of shaft for series 1480 through 1880.

### *Verify Phasing*

Verify that each driveline section is phased as was intended in the design.

### *Measuring the Driveline Installation*

It is just as important to verify the driveline installation as it is to carefully design it. The installation can be verified by using a digital inclinometer to measure the angles and means of measure the distance from one frame-rail to each u-joint center. The measurements on leaf spring equipped trucks should be taken when the vehicle is loaded (i.e. rear body installed and water tank filled or equivalent weight block added). Properly functioning air ride systems do not need to be loaded as the ride height is nearly constant.

The measurements must be taken from the side view and top view of the truck. Measure the driveline lengths and angles using a common reference point on one frame rail to zero an inclinometer. The tool used for measuring the angles in the side view of the vehicle should be a digital inclinometer referenced to a flat area on a frame rail (using the ground will give you false readings) as opposed to a bubble protractor which does not have the required precision. The top view measurements are taken from a common frame rail to the center of each u-joint.

The information can be entered into the form attached to this document (SK-518). NOTE: The transmission and pinion angles can be difficult to obtain. It may be necessary to remove driveline caps or u-joints in order to measure from a known flat surface. If you do not want to disassemble portions of the driveline then a bridge can be used to span over the caps on a full-round yoke to sit on the machined surface or in the case of a half-round yoke you can simply use a small cylinder that is known to be square end to end and place it between the u-joint end cap and the inclinometer as an offset.

When measuring the frame rail offsets in the plan view it may be helpful to use a laser level with a vertical line to transfer the frame rail and u-joint locations from the chassis to the floor. This may make for an easier and more accurate measurement.

A more detailed measuring guide can be found through [Arvin-Meritor \(Measuring and Recording Driveline Angles – Reference Guide TP-98121, see Hale Service Bulletin SB67\)](#).

### Checking the Measurements

The measured angles and offsets should be checked using a program such as The Expert mentioned earlier. Torsional and inertial accelerations should be close to 50% of the limits and should never exceed a maximum of 300rad/sec<sup>2</sup> for torsional accelerations and a maximum of 1000 rad/sec<sup>2</sup> inertial accelerations on both the “drive” and “driven” ends.

A common mistake is to measure the angles without considering the variation of offset from each u-joint center to one particular frame rail. The offsets in the plan view are combined with the measured angles in the side view and together they form an equivalent angle which is what both the torsional and inertial accelerations are calculated from within the analysis software. Without the offset measurements you have not considered the true angle (the equivalent angle) of the shaft.

### Checking for Vibrations

Driveline angles and offsets are a common source of vibration but many other factors can cause vibration in a driveline system. Some of these factors are not easily recognized or detected. The critical speed of a drive-shaft is largely influenced by the length of the shaft, but other factors such as how rigid the mounts are at each end of the shaft have influence as well. A test drive for checking vibration based on “feel” is not the best method. Modern cabs have the potential to insulate the driver from many low and high level vibrations which have the force to cause serious damage. Typically any vibration felt due to a driveline is actually a component somewhere else in the vehicle reacting to the driveline vibration. With rubber mounted driveline components and rubber mounted pump compartments this vibration is isolated and masked from the driver. The best way to reliably detect driveline vibration is to use a tool specifically designed to detect chassis vibrations.

One tool used to check for vibrations is the Kent-Moore EVA2 Vibration Analyzer. This tool can display the three most intense vibrations (measured in G force) and their corresponding frequencies. While no specific data is available for what level of vibration is acceptable in any particular vehicle, a very general range commonly found in solid running vehicles is 0.1 to 0.9 G's when the EVA2 sensor is placed on the bottom of the pump transfer case in all three planes. The EVA2 will pick up vibrations caused by imbalanced shafts, out of phase shafts, improper angles and offsets, and resonance due to two components with similar natural frequencies. The best way to develop an acceptable vibration force range is to test a group of similarly constructed vehicles and establish a baseline on that data.

Some OEM's place vibration sensing equipment on the truck's transmission or on the frame under the cab. While these locations can provide valuable information, the effects on the pump driveline may not be detected as well from these positions as would be if the sensing equipment was mounted directly to the pump transfer case. A consistent method to gather consistent data as part of a quality control program is most important.

Vibrations can develop in one area and be transmitted through the system to another component which then acts as a speaker, amplifying the vibration. This type of effect makes vibrations very difficult to diagnose. Attached to this document is the Dana Vibration Diagnosis chart which is a short guide to help determine sources of vibration. Also available is the [Hale Service SB66 \(Bulletin #957\)](#) to assist with driveline issues.