Rattle: Addressing Gear Noise in a Power Take-Off

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At Muncie Power, the objective of noise and vibration testing is to develop effective ways to eliminate power take-off (PTO) gear rattle, with specific emphasis on PTO products. The type of sound of largest concern in this industry is tonal. Tonal noise can be described as a distinct frequency or range of noise characterized as irritating, annoying and enduring. The testing was not concerned with nor focused on gear whine. Gear weight and size (inertia) also plays a role in vibrations and rattle, but additional testing is required to develop a full understanding of those characteristics and their relationship to rattle. Therefore inertia, gear size and weight are not discussed in this report. The noise and vibration investigated were

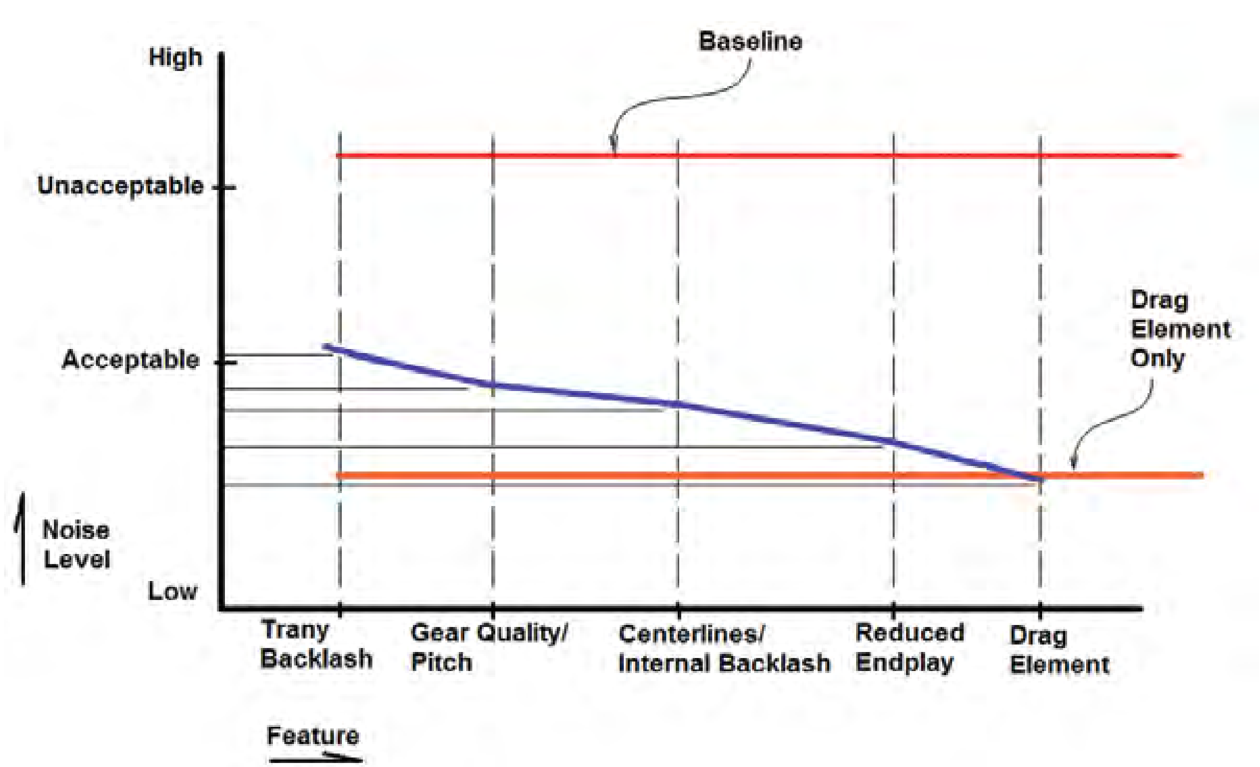

Figure 1—Baseline noise testing conducted on a diesel-powered, class-3 cab with an automatic transmission and recorded noise level.

relevant to transmission speed. The rpm range investigated for this report was as low as 600 rpm and as high as 2,100 rpm. Test data was collected using an array of sensors on our truck—coupled with our data acquisition software—and then compiled and analyzed in our test lab.

Work trucks are much quieter today, which is driving the need for auxiliary power to do the same. Gear noise, whine and rattle are of course not new but are more noticeable now than ever before. In fact, gear noise is more noticeable today as gas and diesel motors and powertrains are much quieter. Given that noise is more noticeable, the engineers conducted tests to identify and isolate particular PTO features that contribute to it. Based on a battery of tests, the engineers have identified the top contributors. The following report and graph highlights and prioritizes those contributors discovered to have the greatest impact on noise and vibration. By addressing them, noise and rattle can be significantly reduced. More importantly, this will improve customer satisfaction through product durability and reliability.

From research, testing and data analysis it was discovered that rattle is a system-dependent phenomenon that may be present or absent, depending on the power take-off and a vehicle's characteristics. This simply means that a power take-off that presents no rattle on one vehicle might rattle on a different vehicle. It is also possible for a power take-off to exhibit different levels of rattle for each side of a vehicle's transmission. Because rattle is a system-dependent phenomenon, it is extremely difficult to control it with a single solution or by using one solution in a particular manner for all PTO rattle. Therefore testing was carried out in distinct steps to better control and analyze the variables.

The first step in the testing process was to create a baseline. Baseline noise testing was conducted on a diesel-powered class 3 truck with an automatic transmission. (See Figure 1 for a depiction of the noise level recorded.) Before the gear set was mounted, meticulous measurements for external backlash, gear profile and lead, internal backlash and end-play were recorded in the QA lab by our CMM and CNC gear checker; all improvements are based on these baseline measurements. Once fully assembled, the gear set was run at idle (approx. 700 rpm), the noise level (dB) was recorded and a baseline was established. The red line in Figure 1 represents the unacceptable sound level from that test. At this point the engineering team began work on specific component features to improve or reduce noise and rattle—one step at a time.

Note that in Figure 1 the graph depicts the effect on the noise level as each feature is addressed. As one can see, the red baseline is well above the acceptable level. Why noise is unacceptable to customers and end users is due to many factors. One in particular is very subjective—i.e., the tonal quality of the noise. In general noise is annoying at best and, worst-case, irritatingly painful. Some tangible features identified by the engineers were excessive backlash between the transmission output gear and the PTO input gear; reduced gear quality; smaller gear pitch; high internal backlash between gears; gear centerlines at top of tolerance; and high tapered bearing end-play. Another feature affecting noise is drag or rotational resistance. The more drag within the system, typically, the less noise and rattle are perceived. (*Drag and its effects are discussed in more detail later in this paper.*)

It is also noted here that with all the testing conducted the graphed data indicates the features are additive. Therefore, each improved feature can reduce noise by some amount. Noise can also be reduced proportionally to the number of features improved; it is a compromise between the benefits of reduced noise versus processing cost. It was discovered one can change many component features, but the backlash between the transmission gear and the

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PTO gear set must be addressed first or the other steps have minimal impact. But the design and control of backlash has its limitations. Backlash is controlled at installation and by gasket selection by the mechanic. Care must be taken to properly mount and install the gear set and torque the fasteners to achieve optimal noise levels. This is in the control of the installer at this point. For the battery of tests this was closely controlled to ensure the reliability of the data. Industry standard ranges from .006" to .012". Intuitively, the lower the backlash setting, the better the noise quality, and that is a very important relationship to manage.

After establishing the appropriate backlash between transmission gear and PTO gear the next feature worked on was gear quality. All the gears in the PTO were addressed. Improving gear quality can be costly; for example—near-net forgings, shaping vs. hobbing vs. grinding, etc. It is important to understand the relationship of manufacturing cost vs. reduced noise benefits. Testing results demonstrated that higher gear quality and gear pitch produced a detectable reduction of noise. The reduction was not only measurable but detectible to the human ear. For example, a change in 1 dB is nearly undetectable to the human ear, but a change of 3 dB is detectable to the average person and almost anyone can hear a change of 5 dB. Thus the tonal quality improved as well. Note gear quality went from a baseline as low as AGMA 6 up to AGMA 10. Gear quality was therefore the second-highest contributor in reducing noise (Fig. 1).

The next step to reduce noise focused on internal backlash and gear centerline control. These are combined since they are so closely related. The engineers determined this is a cost-effective means to reduce noise. Accurate CNC equipment, programming and tooling must be used in manufacturing to hold and repeat tight centerline tolerances. Testing indicated it is necessary to control internal backlash before moving to the next step. From a design standpoint it is important to specify and control internal backlash but the results show this had little effect on reducing rattle and noise detectible to the human ear. Hence, minimal positive impact to the end user. This was an important finding in the test. Testing proved this had the smallest impact on reducing noticeable noise of all the features investigated.

Rattle and noise creates sound waves we feel and, therefore, hear. The waves of sound come from vibration between the gear, shaft and bearing set. If the bearing set is loose (for example excessive end play >.003) the vibrations are more pronounced and the noise is noticeably louder and more annoying. Rattle like that is a huge customer dissatisfaction issue. If the end-play is reduced the noise is reduced proportionally, testing indicates. The baseline end-play was excessive, consequently the noise was unacceptable. When the end-play was reduced by 25% the noise was noticeably reduced as well. However, end-play could not be completely eliminated given the current design; therefore, rattle cannot be completely eliminated. If it were a case in which the bearings could overheat and burn up, then you have a completely different issue to contend with. Bearings need to be sized properly, lubricated appropriately and allowed to react throughout their temperature range. End-play was last on the list of features to address for this set of testing and reporting. There are other component issues effecting vibration and rattle; for example—gear size, inertia, weight, material and geometry, to name a few. These features were not addressed at this time as it would require significant time with physical testing, computer simulation and 3-D modeling to go down that path.

The last feature studied was drag or rotational resistance. This phenomenon was studied to better understand the effect of drag on noise and vibration in a gear train. As Figure 1 shows, the orange line represents the baseline gear set with the addition of drag only; this is drag above and beyond parasitic drag. Parasitic drag is friction or interference due to normal fits and tolerances. This type of drag element is measurable and specifically designed into the PTO (a drag element in and of itself). A drag element by itself will reduce noise if the drag force is significant. For example, a rotational resistance of 10 to 15 in-lbs. is sufficient to have a noticeable effect on noise. A lesser drag element in series with other features discussed will reduce noise as well. The downside of introducing a drag element is the inefficiency it creates; it creates heat and requires power (uses fuel) to overcome resistance forces. The graph also indicates noise was at an acceptable level with only a significant drag element, without other features improved. The question then becomes whether the inefficiencies can be tolerated or whether the operating costs justify the reduction in noise. Drag can come in many forms; for example, tight bearings, excessive hydraulic fluid levels, friction between clutch plates and shaft loads. Other designed parts can be introduced to create drag as well. Drag was last on the list to test because of the negative aspects associated. The graph indicates that noise can be reduced to acceptable levels without drag, but it also shows noise can be reduced by doing nothing other than adding drag.

There are many issues affecting noise and methods to reduce vibration. Some not discussed or tested here are gear size, mass and symmetry; others are geometry, material composition, forged vs. bar, heat-treating, shotpeening, scissor gears and the like. Noise and rattle are important customer concerns today. Gear manufacturers and users of power take-offs are working together to balance noise, rattle and efficiency—as well as cost and value. By utilizing modern tools such as coordinate measuring machines, gear checker, CNC machining centers and data acquisition software, engineers can better control the features and continually work to reduce tonal noise.