Improving In-Process Gear Manufacturing Quality to Meet New E-Drive Demands

The use of noncontact technology for gear quality control

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A combination of international regulations and consumer expectations is driving the demand for reduced noise on all drivetrain components. Further demand is driven by the growing trend towards EVs and HEVs, where noise from ICE is intermittent or no longer present, and the contribution of transmission noise to overall vehicle noise becomes dominant.

Electrified transmissions are subject to several challenges and requirements. What is true is that the number of gear wheels is significantly reduced in electric vehicles due to the use of one or two-speed reducers instead of the classic manual or twin-clutch gearboxes. In return, these are loaded with torque and rpm not previously found in high-volume production.

The other big shift in the automotive industry, the one towards automated driving, is not setting off any alarm bells for gear manufacturers, either. The idea of self-driving cars is currently capturing the industry's attention and, while it is a fascinating trend to follow, having a computer behind the wheel instead of a person is not likely to affect the gear side of the industry too deeply.

To meet the new torque and rpm requirements, the gears for electric drives need to be designed with tighter manufacturing tolerances, especially those dealing with profile and lead features, turning out to become a great challenge for gear manufacturers.

Figure 1—Gears for electric drives need to be designed with tighter manufacturing tolerances, especially around profile and lead features.

While representing a demanding task for manufacturers, it also opens up the opportunity for quality control partners to work more closely with gear producers in order to improve processes and routines. This greater required precision, in fact, results in the need for highly accurate production control.

In this regard, the combination of long-term expertise and the application of newer technologies are key to supporting gear manufacturers who have accepted the challenge of entering the electromobility arena.

The control of the process is paramount and more effective when applied along the entire production chain of a gear. This starts with machine monitoring solutions that detect early breakages on the hob tool through in-process gauging during the grinding operations until the end-of-line measurement and inspection of the finished gear. It is not an insignificant fact that the use of systems for tool analysis to determine optimal edge rounding and surface coating can lead, on average, to a 60 percent increase of the hob utilization. However, what is even more interesting is the adoption and integration of new technologies that quality control companies are ready to develop, embracing innovation and elevating their business tasks.

Earlier, we mentioned the importance of reduced noise on all drivetrain components. Until recently, a noise analysis—better defined as NVH (Noise Vibration Harshness) study—was performed on the assembled gearbox as a functional end-of-line test. However, now that ensuring a silent gearbox has become of paramount importance, the detection of potential noise-producing components must be moved upstream in the process.

The big question that arises is the relationship between the NVH testing of individual gears and the expected NVH behavior on the final transmission assembly. The assumption made in the past regarding ICE is that the gearboxes were so complex and full of gears that it was impossible to identify a direct relationship between the behavior of the individual gears and the complete assembly. With the growing implementation of BEV, it is now believed that the simpler layout of the transmission has made it possible to reveal the impact of the gears on the complete assembly. Moreover, the requirement for NVH testing of the box assembly became tighter in the BEV, forcing gearbox manufacturers to adopt 100 percent NVH testing on the individual gears.

Furthermore, e-drive applications introduce a major difference as compared to traditional transmissions, because drive and coast flanks now have to be considered equally important when a gear is under test. In fact, energy in e-drive configurations flows in both directions—from the motor to the wheels during positive acceleration and from the wheels to the battery pack during brake—so the transmission must be quiet in both conditions.

To achieve this task more easily, new testing technologies are entering the market. Marposs recently introduced the NVH G-EAR testing machine that works on the Single Flank testing methodology to help its customers identify potential noise-producing gears prior to the assembly into the gearbox. The single flank testing principle is based on one master gear meshing with the component under inspection to detect macrogeometry (nicks, runout, etc.) and microgeometry (gear mesh excitation, ghost orders) defects that are responsible for gear whine and noise phenomena. The ability to achieve high torque and rotational speed, as well as the possibility of adjusting them at will during testing, is one of the major benefits of the application. This allows for the testing of gears in operating conditions almost comparable to those found in the final e-drive.

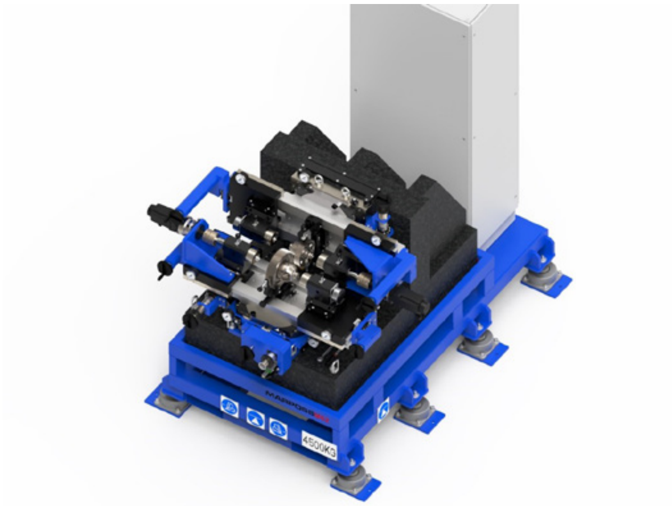

Figure 2—This gear tester from Marposs works on the single flank testing method where a master gear meshes with the component under inspection, identifying defects not detectable with traditional production tests.

Evaluating NVH based upon a single component enables the identification of defects such as microgeometry errors on a gear, helping avoid issues that are much harder to solve at the assembly stage. This represents an invaluable benefit in terms of time and money saved for manufacturers. Moreover, the NVH test allows the identification of defects on the gear flanks that are not normally detectable with the traditional production quality tests (double flank roll checkers, DOB/MdK measurements). These tests are very effective at the early or intermediate stages of the manufacturing process (after hobbing or shaving operations, before and after the heat treatment), while their contribution no longer represents a "plus" when the gears are already ground, polished or honed, which is a normal requirement for gears used in e-mobility.

For instance, a gear that is machined within the manufacturing tolerances and passes the traditional measurements checks may still produce noise at certain frequencies in the gearbox. This event, known as the ripple phenomenon, is responsible for creating a frequency of an amplitude that exceeds the expected threshold (ghost orders). The ghost orders are due to microsurface issues in the profile and lead directions of the gear flanks.

The main source of noise has to be sought in the accelerations that repeat consistently at every part revolution; a part that is geometrically perfect could be noisier than one with a small number of defects as the presence of defects on the teeth allows the energy to spread out. Gear manufacturers are struggling to understand how to introduce a controlled number of variations in the parts to achieve the goal of a silent gear. And here comes the tricky point: from an engineering standpoint, the gear has to be designed and manufactured with the lowest number of possible imperfections to ensure proper mechanical reliability. Yet, on the other hand, the challenge is to introduce form deviations to reduce the amplitude of certain orders during meshing.

Suitable for incorporation into production, the machine is able to achieve 100 percent inspection of tasks, such as identifying the so-called "ghost orders" that represent the major contribution to gear noise in most cases.

While the single flank test is run at a lower speed of 30 rpm, a torsional acceleration test is also performed with measurements taken at high speeds of 500–3000 rpm, at a constant speed/constant torque, at constant speed/ramp torque and at ramp speed/constant torque.

The signal of the sensor is elaborated to obtain a fast Fourier transform (FFT) that shows the amplitude of the frequencies of vibrations, identifying the contribution during different stages. The angular TE (Transmission Error) values are converted into linear data.

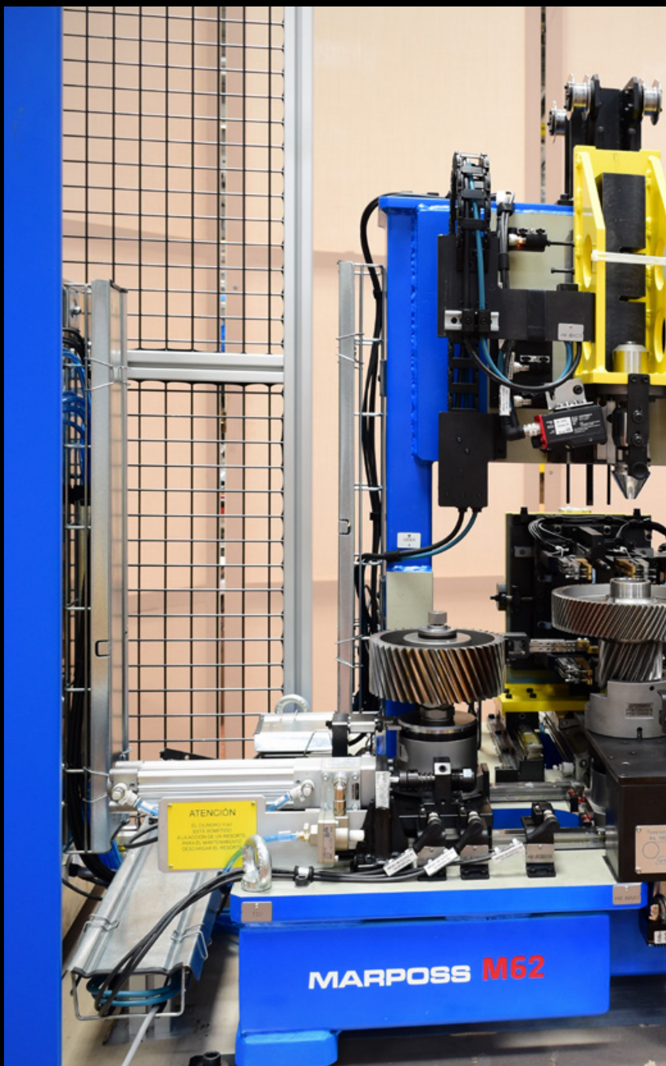

Figure 3—In addition to single flank testing, a torsional acceleration test can also be performed, helping to identify defects that might otherwise only be revealed once the gearbox is assembled.

The Fourier analysis can be used to understand the possible root causes contributing to the nonconformity of the noisy gear. The type of peaks detected over the FFT spectrum of the gear may have different origins, but all of them are related to the manufacturing process. For example, it might be due to an offset (misalignment) that occurred to the grinding wheel, generating eccentricity. In other cases, it may indicate local pitch errors or profile errors due to a division error on the machine tool, or a nonconformity could occur due to an unbalanced grinder or from the vibration of the grinding tool.

Retrieving this type of information can be vital to correctly provide feedback to the manufacturing process to ensure the quality of the gear product.

Manufacturers that decide not to adopt an individual NVH gear tester must cope with the concrete possibility of getting a higher number of scraps and noisy gearboxes, without comprehending the real reason for the nonconformity. If a gearbox fails the end-of-line test once it is completely assembled

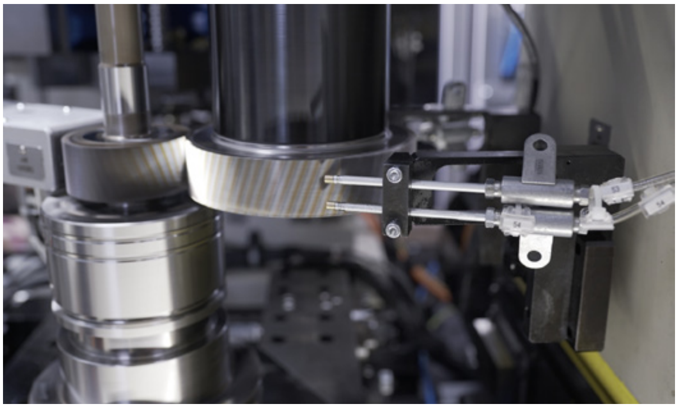

Figure 4—Identifying potential gear defects at the component level is crucial to eliminating transmission noise.

and, consequently, one or more gears are suspected as being the source of the error, then this is often followed by a manual disassembly, the replacement of each gear and the performance of a new measurement of those gears in the laboratory. It appears clear that this approach is time-consuming and far from cost-effective. Other than that, as was stated earlier, is that even remeasuring the gear (with a traditional gear measuring Instrument) might not ensure the identification of the failure. As a matter of fact, a “perfect” gear may still be the cause of any gearbox noise.

The NVH G-EAR tester was developed for gear testing with a specific focus on EV applications, but it is really an evolution of well-known and established technology. The real achievement in gear quality control is the use of noncontact technology for measuring and inspecting gears on the shop floor.

In this respect, Marposs has recently introduced another system that uses laser profile sensors and the optical triangulation principle. As compared to dedicated gear gauging systems or gear laboratory machines, the use of laser technology enables the system to easily adapt to inspecting a variety of gear sizes and shapes in a very short time. The cycle time, in fact, is key. And being fast does not normally match with accuracy.

We previously mentioned that profile and lead characteristics have reached tighter tolerances in gears for electric vehicles, forcing gear producers to seek solutions to keep those parameters under control while still achieving production rates. That is where the noncontact technology applies best.

The laser profilers project a laser line on the gear at a specific angle, collecting data to generate the entire Z-X profile through an image sensor placed behind the optical receiver. The gear is then quickly rotated 360 degrees to collect data points from movement along the Y axis, which is combined with the Z-X

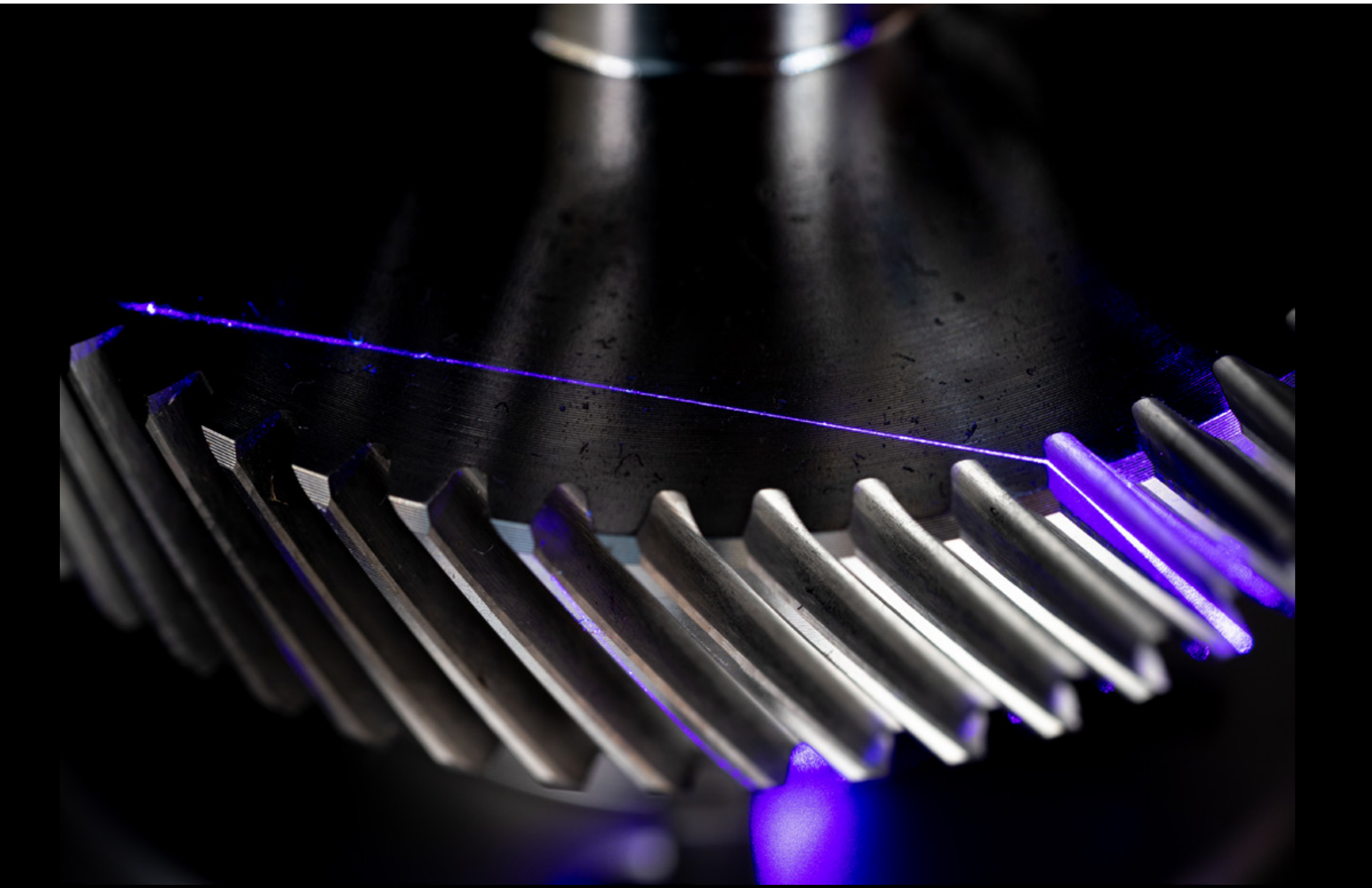

Figure 5—The application of noncontact technology—such as lasers and cameras—is also evolving to tackle the increased need for gear measuring in e-drives.

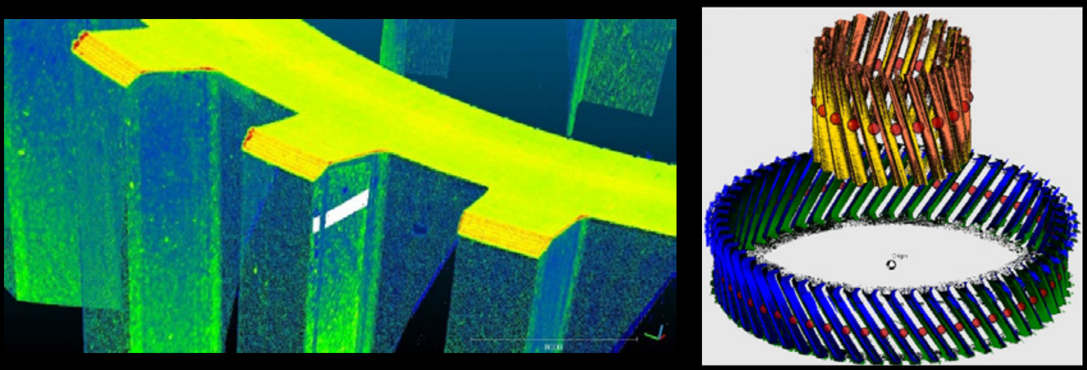

Figure 6—In Marposs' newest system laser profile sensors and the optical triangulation principle help reconstruct a 3D model of the component being measured.

profile to create a complete 3D reconstruction and representation of the part in less than a minute, made possible through specific software algorithms. The system then executes the requested measurement and inspection tasks. Line operators can easily review images and navigate to the desired level of detail to identify any anomalies.

In addition to quality control capability, the multiple laser heads create a point cloud with such a high level of spatial resolution that the details provide a reliable dataset that can also be used for design reviews and final project validation.

With increased demands for lower-noise drivelines driven by the EV market, more pressure is being placed on design and production to solve gear whine and noise issues quickly and efficiently, and this is where technologies such as these will play a key role.

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