Renewable Energy

*Wind Turbine Training System*

# Nacelle Operation and Maintenance

Courseware Sample
88765-F0

Lab-Volt®

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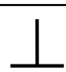
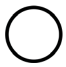
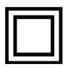
# Safety and Common Symbols

The following safety and common symbols may be used in this manual and on the Lab-Volt equipment:

| Symbol | Description |
| --- | --- |
| **⚠ DANGER** | **DANGER** indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury. |
| **⚠ WARNING** | **WARNING** indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury. |
| **⚠ CAUTION** | **CAUTION** indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury. |
| **CAUTION** | **CAUTION** used without the *Caution, risk of danger* sign , indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage. |
|  | Caution, risk of electric shock |
|  | Caution, hot surface |
|  | Caution, risk of danger |
|  | Caution, lifting hazard |
|  | Caution, hand entanglement hazard |
|  | Direct current |
|  | Alternating current |
|  | Both direct and alternating current |
|  | Three-phase alternating current |
|  | Earth (ground) terminal |
|  | Protective conductor terminal |

# Safety and Common Symbols

| | |
|---|---|
|  | Frame or chassis terminal |
|  | Equipotentiality |
|  | On (supply) |
|  | Off (supply) |
|  | Equipment protected throughout by double insulation or reinforced insulation |
|  | In position of a bi-stable push control |
|  | Out position of a bi-stable push control |

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# Preface

Wind power has been used for centuries for tasks such as grinding grain, pumping liquids, and driving machinery. It is only in the 1890's that the first wind machines used to produce electricity were built in Denmark, Scotland, and the United States. This type of clean and renewable energy has since evolved to such an extent that it now meets a significant portion of the electricity demand in several countries and its use continues to expand.

This course on wind turbines teaches the production of electrical energy from wind power with a focus on operation, troubleshooting, and maintenance of the equipment. Basic electrical and hydraulic knowledge is recommended before starting the course. The manuals present the different parts of a wind turbine and provide useful information targeted for the future wind turbine technician and operator.

The Wind Turbine family of training systems consists of the Nacelle, Model 46122, the Electrical Pitch Hub, Model 46123, and the Hydraulic Pitch Hub, Model 46124. A Power Generation option (P/N 88756) can be added to the Nacelle to send some power back to the local three-phase electric power system.


**Wind Turbine training systems.**

A specific manual corresponds to each of the four main components listed above. It is recommended that you start by using the manual concerning the nacelle. However, the other three manuals can be covered in any order the instructor deems appropriate.

We sincerely hope that your learning experience with this training system will be the first step toward a successful career.

# About This Manual

## About the Nacelle Operation and Maintenance course

This course explains how to operate, troubleshoot and maintain a wind turbine nacelle.

Unit 1 introduces the components and the user interface of the Nacelle trainer.

Unit 2 focuses on the drive train system that transforms wind power into electrical power.

Unit 3 analyzes the hydraulic system that is used to brake the drive train and the yaw system.

Unit 4 reveals the control logic behind the nacelle trainer during normal operation and explores the alarm conditions.

Unit 5 is mainly aimed at understanding the electrical schematics that is provided with the nacelle trainer for troubleshooting purposes.

Unit 6 consists of two troubleshooting exercises.

## Safety considerations

Safety symbols that may be used in this manual and on the Lab-Volt equipment are listed in the Safety Symbols table at the beginning of the manual.

Make sure that you are wearing appropriate protective equipment when performing the tasks requested in hands-on exercises. You should never perform a task if you have any reason to think that a manipulation could be dangerous for you or your teammates.

## Systems of units

The values of measured parameters are expressed using the SI system of units followed by the values expressed in the U.S. customary system of units (in parentheses).

Sample Exercises

Extracted from

Student Manual

# From Wind to Electrical Power (Drive Train System)

**UNIT OBJECTIVE**

When you have completed this unit, you will be familiar with the elements composing the wind turbine drive train system and the type of maintenance they require.

**DISCUSSION OUTLINE**

The Discussion of Fundamentals covers the following points:

- The drive train system
- Rotor hub
  *Hub types. Blade pitch bearings. Rotor blade aerodynamics.*
- Low-speed (main) shaft
  *Materials. Hollow Versus Solid Shafts. Pillow Block Bearings.*
- Gearbox
  *Gear drive basics. Parallel vs. planetary arrangement. Gear types. Efficiency and oil temperature. Speed monitoring.*
- Generator coupling and shaft alignment
  *Coupling. Shaft misalignment. How to align machinery shafts.*
- Vibration analysis
- Bolt torque
- Lubrication
  *Oils. Greases.*

**DISCUSSION OF FUNDAMENTALS**

## The drive train system

The mechanical drive train, also called "transmission system", is the core of a wind turbine. It goes from the hub, where wind kinetic energy is transformed into mechanical energy, and goes all the way down to the generator shaft, where electricity is produced. A common drive train design includes the following components: hub, low-speed shaft (and bearings), gearbox, high-speed shaft, rotor brake, coupling, and generator shaft.

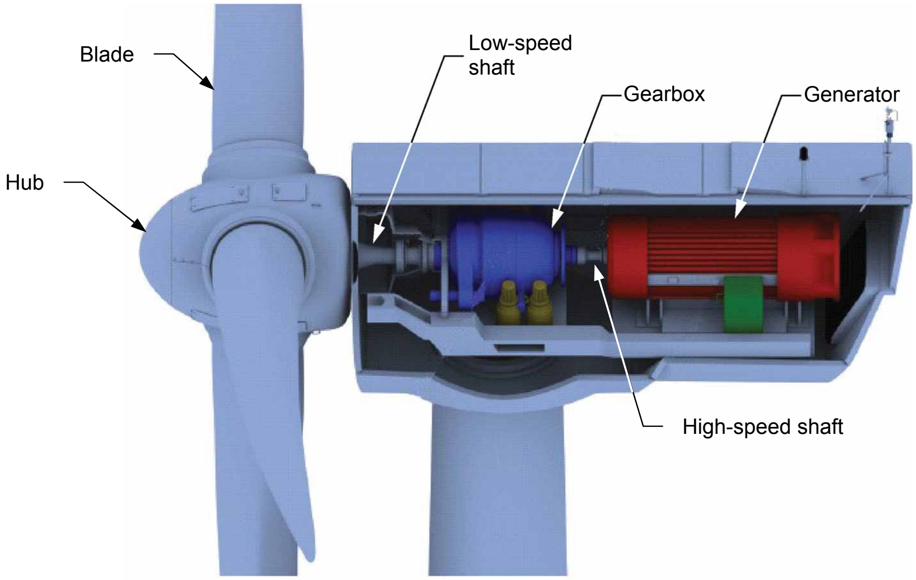



**Figure 2-1. Mechanical drive train layout.**

As shown in Figure 2-1, these components work together as follows:

- The wind spins the turbine blades.
- The blades are integrated into a rotor hub, which is connected to the low-speed shaft. When the blades spin, the shaft turns.
- The low-speed shaft is connected to a gearbox. Inside the gearbox, a set of gears makes the high-speed shaft rotate faster than the low-speed shaft.
- The high-speed shaft is coupled to the generator, which produces electricity.

The electrical output power of a wind turbine is a function of the wind speed, the turbine angular velocity, and the efficiencies of each component in the drive train system.

We saw in Unit 1 that the most energy that can be converted from the wind into electricity is a theoretical value of 59%, called the Betz limit. However, the overall performance of real wind turbines is always lower than this value. Not only do the blades not extract this magnitude of wind power, but all the components of the drive train system more or less exhibit mechanical, thermal, and electromagnetic losses.

## Rotor hub

The hub is the part of a wind turbine where the blades and the rotor shaft connect. Small wind turbines may have fixed blades, but most wind turbines are able to vary the angle of the blades to control the rotor speed and keep the rotor from turning in winds that are too high or too low to produce electricity. This feature is called "blade pitch control" and requires additional components to move the blades.

> The electrical and hydraulic pitch hubs courses put more emphasis on hub construction and how exactly the blades are angled.

### *Hub types*

The two main existing hub types are electrical and hydraulic pitch hubs, depending on which type of actuator is used for pitch control. Regardless of the hub type, each blade is connected by a bearing onto the hub. The blade pitch bearing is designed to allow the blade to pitch around a pitching axis. The hydraulic actuator or electric gear-driven motor and controller are housed in the hub.

### *Blade pitch bearings*

A four-point contact ball slewing bearing is used on the yaw system of the nacelle trainer.

Blade pitch bearings allow the blades to rotate around their axis while being robust to body deformation. Common bearings for this type of application are four-point contact ball slewing bearings. Figure 2-2 shows where these bearings are located on a hub and what they look like.

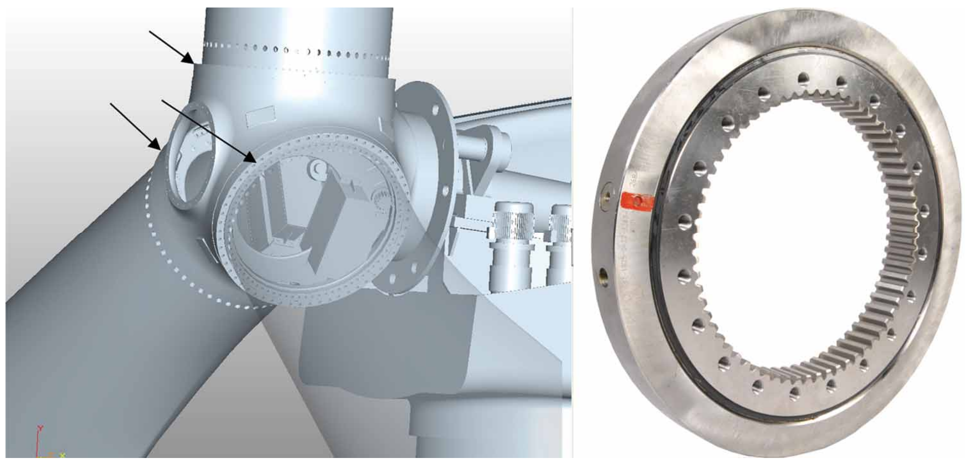


**Figure 2-2. Four-point contact ball bearings.**

### *Rotor blade aerodynamics*

Wind machines can utilize two types of aerodynamic force to extract power: drag and lift. Drag is the most obvious form, as it is the one against which you fight when you are facing the wind (Figure 2-3). It can be defined as the sum of forces acting on an object parallel to the relative fluid flow direction.

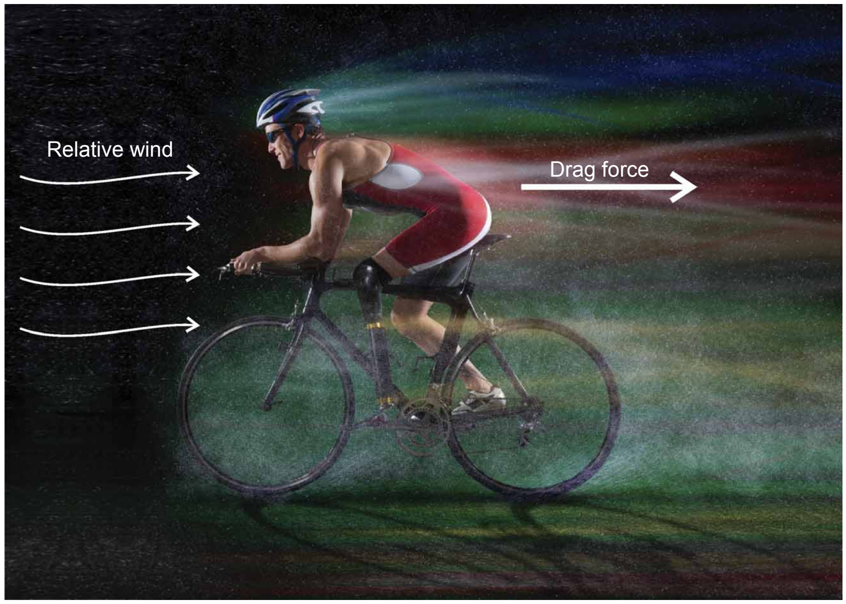



**Figure 2-3. Drag force.**

Lift, on the other hand, is perpendicular to the oncoming flow direction. It is caused by deflection of the flow on the surface of an object. Airplanes are remarkable applications of this principle, considering that the lift force exerted on the wings suffices to maintain the aircraft in the air.

The key in creating lift force lies in the shape of the deflecting object. One way of understanding lift intuitively is to imagine the flow path and the pressure created on the upper and lower surfaces of a wing (Figure 2-4). In short, the stretching of the air along the top path thins the air and produces a lower air pressure, creating a net upward force.

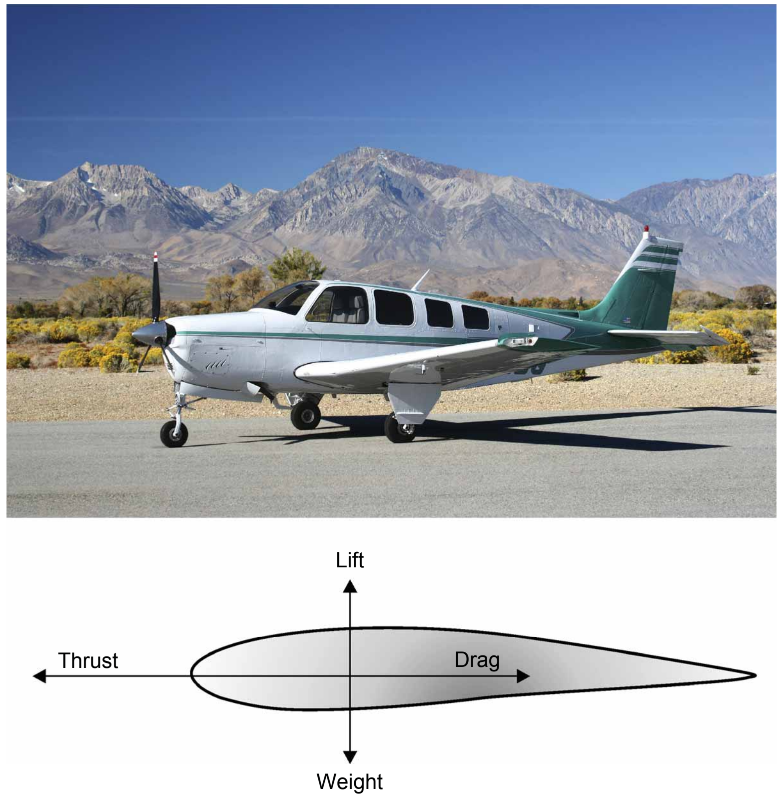



**Figure 2-4. Forces acting on the cross-section of an airplane wing (airfoil).**

Figure 2-5 depicts a wind turbine in operation. Viewed from the front of this nacelle, the blades turn in a clockwise direction.

**Figure 2-5. Moving blades on a wind turbine.**

Some wind turbines include tip brakes mounted at the end of the blades that provide aerodynamic braking.

If we look at a single blade (Figure 2-6), we can observe that it has two long edges, known as the leading and trailing edges. The blade tip refers to the end farthest from the hub. The blade root is the end bolted to the hub.

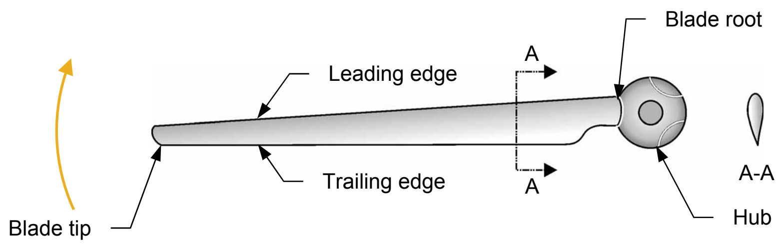



**Figure 2-6. Rotor blade attached to the hub.**

*Do you find some similitude between the cross-sectional view of the blade and the airplane wing of Figure 2-4?*

The leading edge is thicker and tapers down to the thinner trailing edge (see the A-A cross-section in Figure 2-6). This is the blade's aerodynamic profile. Variations in this profile can affect the blade's performance at different wind speeds.

Figure 2-7 is a view of the opposite blade from the inside of the hub. You can see that the **blade pitch** is the angle between the hypothetical blade centerline and the hub's plane of rotation. This position is controlled by the electrical or hydraulic pitch mechanism. The **feathered position** corresponds to a blade pitch of 90 degrees, whereas a normal operating position is closer to 5 degrees for reasons that will be explained shortly.

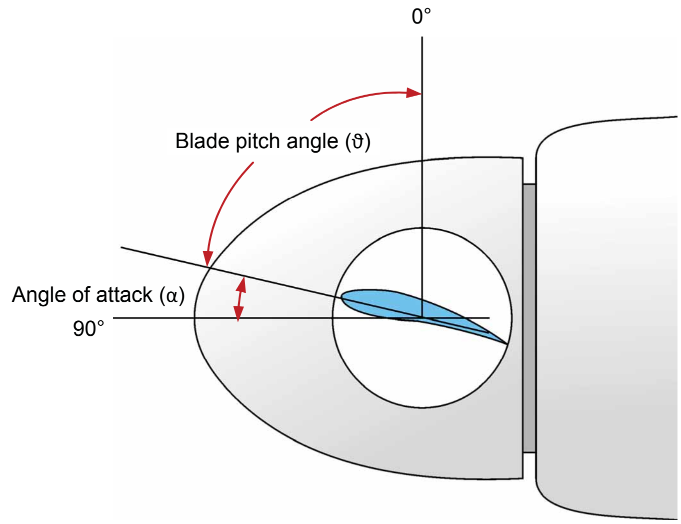



**Figure 2-7. Pitch angle (looking through the hub).**

Figure 2-8 shows what happens when air flows around a stationary blade in feathered position. In this situation, air flow exerts an equal and opposite force on either side of the blade.

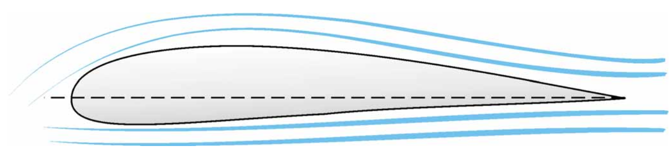


**Figure 2-8. Airflow around the blade in feathered position.**

Slightly tilting the blade has an important effect on the blade. As shown in Figure 2-9 (for a blade which is at such a point in its course that the blade is parallel to the ground), a small angle of attack is enough to create lift and start blade rotation.

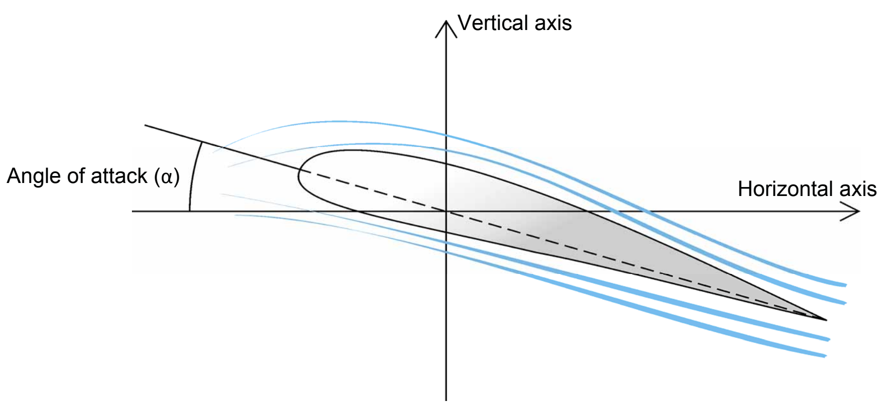



**Figure 2-9. Blade just out of the feathered position.**

As the rotor and blades gain rotational speed, the wind component of the airflow hitting the blade becomes relatively less important. Therefore, the blade is slowly pitched to the vertical so that it remains as aerodynamic as possible, yet still generates lift that is converted in driving torque by the drive train system.

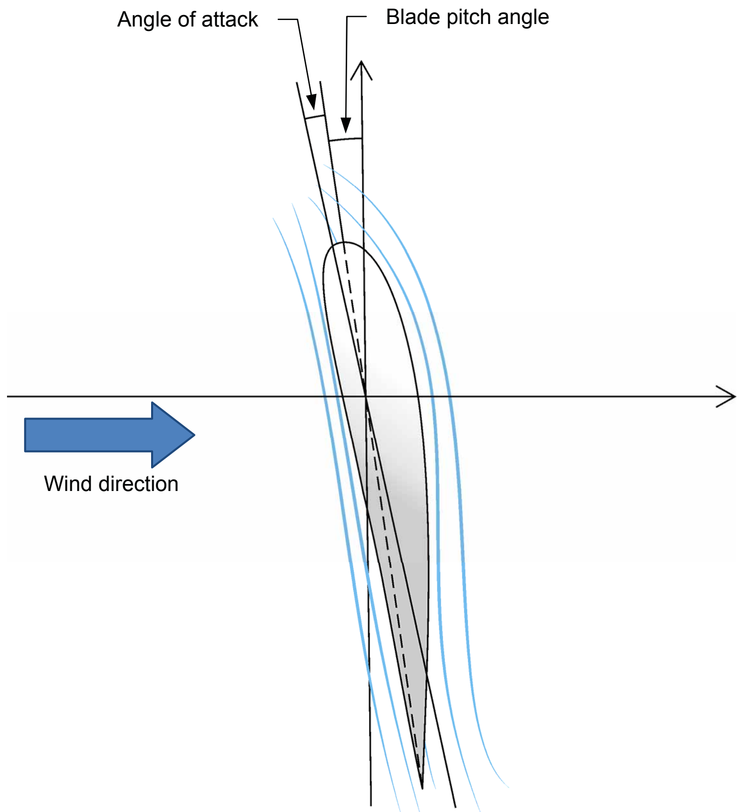



**Figure 2-10. Blade operational position (almost vertical).**

During power generation, blades are pitched slightly in or out of the wind in order to maintain a constant rotational speed. When the wind turbine is stopped, blades are pitched toward the feathered position, which slows down the rotor aerodynamically.

## Low-speed (main) shaft

The low-speed shaft, also called the main shaft (Figure 2-11), provides the transfer of torque from the rotor to the rest of the drive train system. The shaft is supported by bearings. Depending on the design of the gearbox, the shaft and the bearings may be integrated into the gearbox, or may be completely separate from it, mounted in pillow blocks, and connected to the gearbox by a coupling.

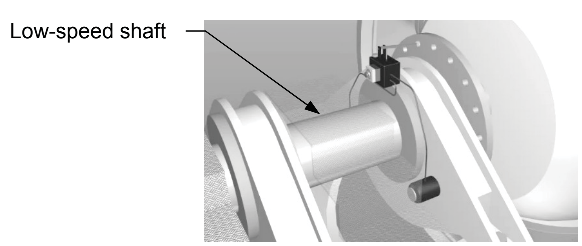



**Figure 2-11. Low-speed shaft mounted in bearings.**

### *Materials*

The most common shafting materials are cold-drawn carbon steel, chrome-plated steel, and tempered steel. When greater shock resistance and strength are required, alloy steel bars are used instead. Also, if surface wear resistance is a dominant factor, corrosion-resistant steels (carburizing-grade steel) can be used.

### *Hollow Versus Solid Shafts*

Hollow shafts (Figure 2-12) are lighter than solid shafts of comparable strength and diameter, but can be more expensive to manufacture. For a shaft that mostly carries torsion loads (like in a wind turbine application), the outer elements with the greatest radii carry the highest stresses and the center core elements contribute little to the function of the shaft. Therefore, hollow shafts have better strength-to-weight ratio.

The through bore can be utilized for various purposes, including:

- Cooling of the shaft. In order to prevent the shaft temperature from rising due to friction, fittings can be mounted on the ends to introduce various cooling medium (air, water, etc.) through the hollow bore.
- Electrical wire and other plumbing components can be run through the bore.

Some large wind turbine hollow shafts are so large that they can provide access to the hub to maintenance personnel.

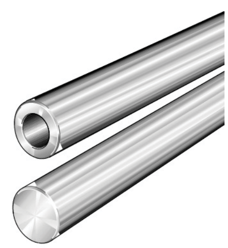


**Figure 2-12. Hollow and Solid Shafts.**

### *Pillow Block Bearings*

Pillow block bearings such as the one depicted in Figure 2-13 are used in many types of machines and equipment that have no housing for the bearing. Most pillow block bearings incorporate self-aligning bearings that do not require precision mountings.

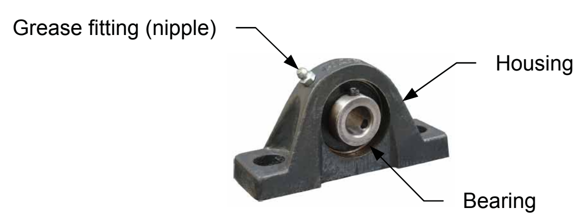



**Figure 2-13. Pillow Block.**

A grease fitting is sometimes included for lubrication. Periodic lubrication of pillow block bearings is required to replace dirty lubricant and compensate for losses due to leakage and evaporation. A grease gun or an automatic lubrication system can be used to pump grease through a fitting into the bearing.

## Gearbox

Typical generators with two pairs of poles will have a synchronous speed of 1800 RPM (60-Hz grid) or 1500 RPM (50-Hz grid) while nominal rotor speeds are much lower.

The main purpose of a gearbox in a wind turbine is to increase the rotational speed at the low-speed shaft in order to fit the needs of the electric generator at the high-speed shaft. Different electric generator systems have different requirements in terms of the generator shaft speed. Some concepts with a great number of poles in the generator even allow for direct drive; that is, the rotor drives the electric generator directly without a gearbox. However, a generator without a gearbox is much larger. This can be an unacceptable compromise in some situations.

### *Gear drive basics*

Gear drives are a rigid means of transmitting mechanical power between close shafts through the meshing action of their teeth, as shown in Figure 2-14. When two gears mesh together, the smallest gear is called the pinion. It can be either a driving or a driven gear.

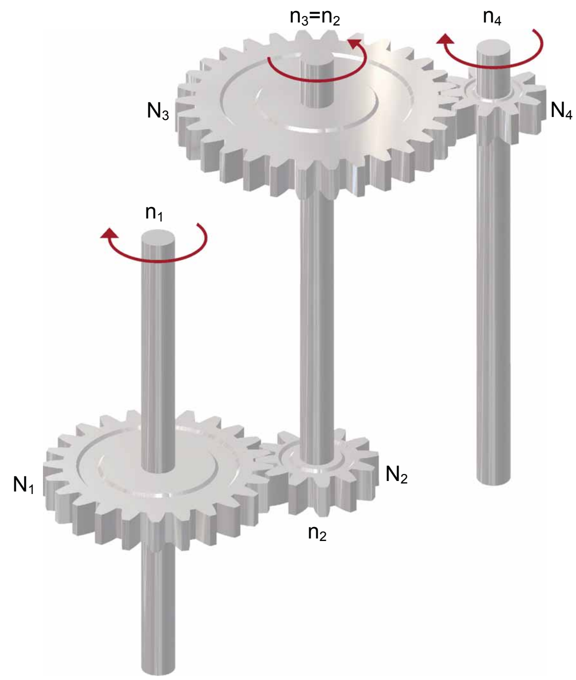



**Figure 2-14. Two stages of reduction (from right to left).**

Gears can change both the orientation and speed of a rotary motion. They provide a very efficient way of transmitting power without slippage. One important characteristic of gears is their number of teeth (N).

If the output gear has more teeth than the input gear, the ratio is greater than one and the output torque is proportionally greater, but the output speed is proportionally lesser.

When two meshed gears are involved (one gear stage), the ratio of gear teeth between the gears can be used to derive the rotational speed, torque, and gear ratios. Equation (2-1) shows how these parameters are related. It should be noted that the direction of rotation of the input and output shaft is opposite.

$$R = \frac{N_2}{N_1} = \frac{n_1}{n_2} = \frac{T_2}{T_1} \tag{2-1}$$

where
- $R$ is the gear ratio
- $N_1$ is the number of teeth of the driving gear
- $N_2$ is the number of teeth of the driven gear
- $n_1$ is the speed of the driving gear in RPM
- $n_2$ is the speed of the driven gear in RPM
- $T_1$ is the torque on the driving gear in lbf·in
- $T_2$ is the torque on the driven gear in lbf·in

It is possible to rearrange Equation (2-1) to determine any of the parameters. For example, if the speed of the driven gear must be determined, the following relation can be used:

$$n_2 = n_1 \cdot \frac{N_1}{N_2} \tag{2-2}$$

**EXAMPLE**

A small motor drives a simple mechanism comprising two shafts and gears in parallel. The driving shaft rotates at 30 RPM, the driving gear has 40 teeth, and the driven gear has 25 teeth. What is the speed of the driven shaft $N_2$?

**Solution**

$$n_2 = n_1 \cdot \frac{N_1}{N_2} = 30\ \text{RPM} \times \frac{40\ \text{teeth}}{25\ \text{teeth}} = 48\ \text{RPM}$$

Interestingly, when three gears are meshed in series, the number of teeth of the middle gear has no influence on the total ratio. However, the rotation of the output gear reverses direction with respect to the two-gear scenario.

When multiple stages of reduction are used, the total gear ratio is obtained by multiplying the individual ratios of each reduction stage by the other.

### *Parallel vs. planetary arrangement*

A single-stage gearbox implies a minimum of two shafts. A two-stage gearbox has three shafts minimum.

Because of the high ratio needed, gearboxes for wind turbines are generally built with multiple stages of planetary and/or parallel shaft gearing. Figure 2-15 shows what planetary and parallel shaft gearings look like.

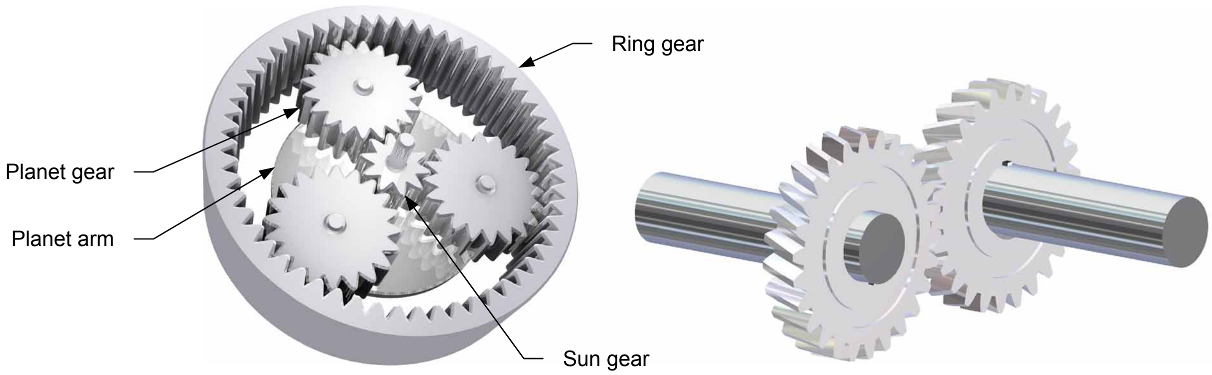



**Figure 2-15. Planetary and parallel shaft gearings.**

The planetary gears consist of a sun gear, or center pinion; a ring gear; planet gears, or idler gears; and a planet arm. In this configuration, planet gears rotate in the opposite direction as the sun (middle) gear. The fixed ring gear causes the planet gears to travel as a group in the same direction around the sun gear at a slower speed, thus turning the planet arm. This type of system can also be arranged so that the planetary group is fixed, and the ring gear is connected to a shaft and free to rotate.

Planetary gearboxes are often preferred in bigger wind turbines, because of the lesser weight required for a given ratio. However, parallel shaft configuration is more popular with smaller turbines, since it is cheaper and mass is less critical.

*Gearboxes can be very noisy. For example, measured values ranging from 100 dB to 105 dB are common near large planetary gearboxes. In comparison, a similar parallel-shaft gearbox should generate 75 to 80 dB.*

### Gear types

Spur and helical gears are commonly used in wind turbines (Figure 2-16). While spur gears are rather familiar, here is a quick note on helical gears.

Helical gear teeth are oriented at an angle. This provides an overlapping tooth engagement, which provides a smoother, quieter operation. Because of this, they run with less vibration and at a higher speed than spur gears. However, this configuration produces a thrust load, or axial load, that must be supported by the bearings.

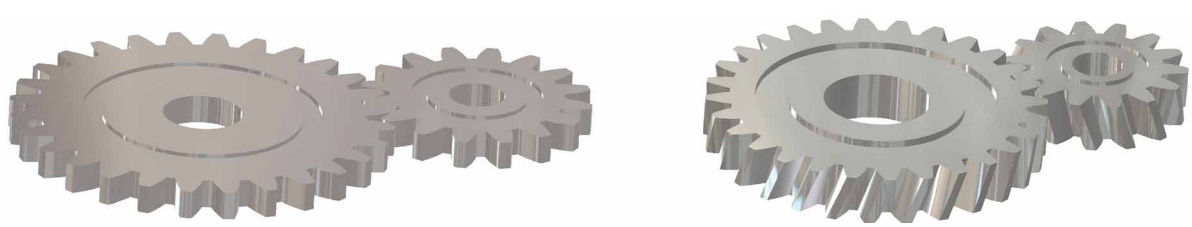


**Figure 2-16. Spur and helical gears.**

### *Efficiency and oil temperature*

Power losses within the gearbox are relatively small (i.e., of the order of 1 or 2% per stage). They are mainly caused by gear tooth friction and oil splash losses, generating heat and noise.

Gearboxes are designed to operate within a specific temperature range. Sometimes, the ambient temperature or the heat generated inside the gearbox causes the oil to fall outside these safe operating conditions. If oil is too cold, the shafts rotate with more difficulty, increasing the friction load and diminishing the overall efficiency. If oil is too hot, it degrades faster and viscosity diminishes significantly, causing wear.

For all these reasons, temperature monitoring and gearbox heating/cooling systems are very common in wind turbines.

### *Speed monitoring*

The input and output shaft speeds need to be monitored at all times to reveal possible problems. In particular, slippage can be exposed when the ratio between the output and input speeds is lower than the expected value.

## Generator coupling and shaft alignment

> The generator is viewed from a mechanical standpoint in this unit, but it will be explained more thoroughly in Unit 5.

### *Coupling*

The purpose of couplings is to transmit rotary power between shafts. Different coupling types exist that can be used in a wind turbine to link the high-speed shaft to the generator drive shaft. Some coupling types are rigid, but most of them have some degree of flexibility, hence their name “flexible couplings”. Coupling manufacturers specify radial, axial, and angular tolerances (i.e., maximum permissible misalignments) in tables.

Besides flexibility, the possibility to detach the coupling for practical reasons and the presence of a rupture joint for safety reasons are two interesting features that are implemented in various coupling designs.

### *Shaft misalignment*

Figure 2-17 shows the two main types of machinery shaft misalignment: parallel (also called “offset” or “radial”) and angular. The misalignment can be in the vertical plane as shown, but it can also be observed in the horizontal plane.

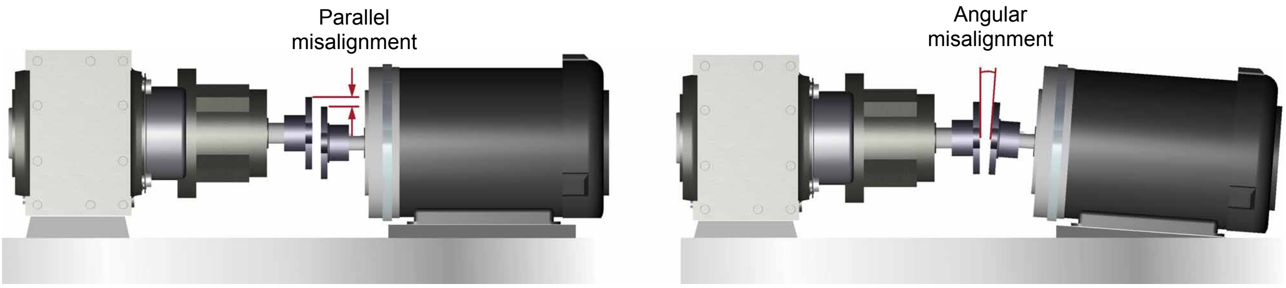



**Figure 2-17. Parallel and angular misalignment.**

There is a variety of reasons why the shaft of the generator must be properly aligned with the high-speed shaft:

- Avoiding premature bearing and seals failure
- Minimizing shaft fatigue
- Reducing vibration
- Increasing generator efficiency and hence, minimizing power losses and over-heating

Shaft alignment is done when the machine is put in service and anytime a gearbox or generator is replaced. A good practice is to check alignment again after a certain period of time, according to the wind turbine maintenance schedule.

### *How to align machinery shafts*

Figure 2-18 shows two tool types that can be used for shaft alignment: mechanical (stylus or dial indicator) and optical (laser) kits. In all cases, the alignment kit is divided in two parts, one for each side of the coupling.

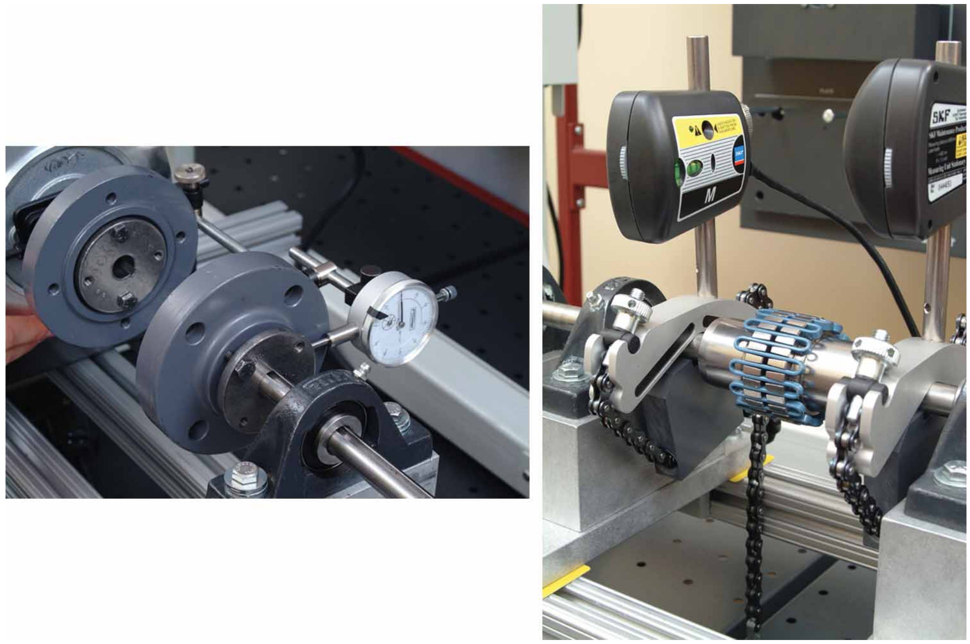


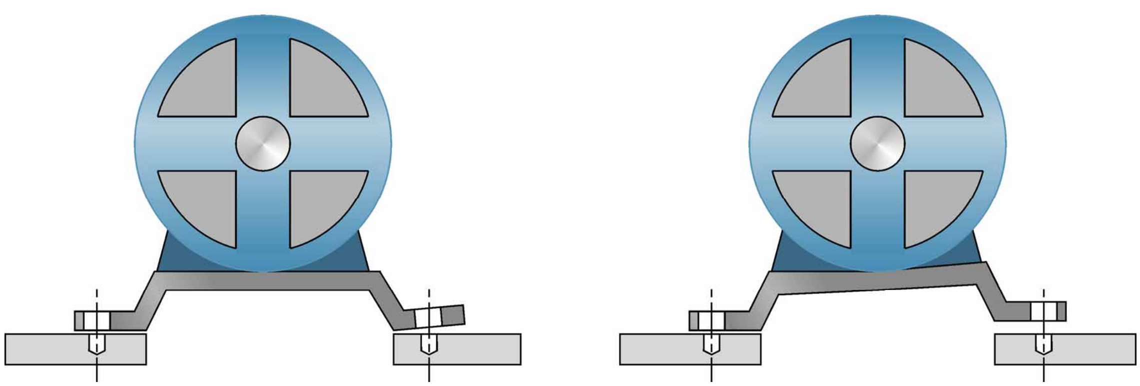
**Figure 2-18. Dial indicator and laser alignment kits.**

The same general steps apply whichever tool you use. Take note that steps 3 and 4 can be done in a different order:

1. Install one part of the kit on either side of the coupling. The two measuring parts (styluses or laser emitter and receiver) must be properly positioned.

2. Make sure the generator is resting equally on four feet (Figure 2-19).

*The condition in which the machine is standing on three feet is called soft foot and makes alignment particularly difficult because it makes the machine unstable. You can detect a soft foot by loosening each hold-down bolt individually and measuring the distance, if any, between the foot and the base with a feeler gauge. Place shims to correct angular or parallel soft foot if necessary.*



(a) Angular. (b) Parallel.

**Figure 2-19. Angular and parallel soft foot.**

3. Perform vertical alignment (angular and parallel).

4. Perform horizontal alignment (angular and parallel).

5. Verify the alignment. Repeat steps 3 and 4 again until you obtain results within the specified coupling tolerance.

6. Write the alignment report.

## Vibration analysis

Because of the many forces that act upon or inside them and the way they are built (slender, made of almost elastic materials), wind turbines are highly subject to vibration.

Vibration has negative impacts on components' dynamic load, the quality of the generated power, and the noise level. A careful design of a wind turbine necessitates assessment of the possible resonance problems to minimize vibration at least during normal operation conditions.

Careful design is however not enough. Vibration sensors need to be placed at some critical points to stop the system when safe vibration levels are exceeded. Moreover, maintenance teams monitor changes in vibration levels to detect alignment problems, bolt loosening, or component wear.

## Bolt torque

Even though all fasteners are checked for proper torque during the installation of the wind turbine, care must be taken to re-check the torque of some critical bolts periodically. This includes blade and drive train fasteners, which are particularly subject to vibrations, and hence, to loosening.

Torque check is done with a torque wrench. Technicians can use bending or click type torque wrenches on small wind turbines, but larger turbines necessitate a hydraulic torque wrench because of the higher torque needed.

**CAUTION**

Never use a torque wrench for disassembly. Applying excessive force could damage the torque wrench and affect its precision. Use another tool instead, such as a ratchet, a breaker bar, or a wrench.

If a bolt seems damaged during the torque check, it must be removed and replaced.

## Lubrication

Every machine with moving parts experiences friction. Friction must be controlled and reduced in most mechanisms since it is a cause of premature wear. Lubricants such as oils and greases are applied whenever friction control and reduction are required. This prevents direct metallic contact between the rolling elements, raceways, and edges. It also prevents wear and protects the bearing surfaces from corrosion. Lubricants also dissipate heat and help exclude contaminants.

The choice of a suitable lubricant and method of lubrication for each application is therefore important, as is correct maintenance. The manufacturer's instructions on maintenance schedule and suggested lubricant should be followed diligently.

### *Oils*

Kinematic viscosity is often expressed in units of centistokes (cSt). 1 cSt is equivalent to 1 $mm^2/s$ in the SI system of units. Kinematic viscosity can be measured using a viscometer.

Oils are either natural or synthetic liquid lubricants offered with a wide variety of properties. They are usually mixed with additives to enhance physical properties such as wear, oxidation, and rust prevention. One of the most important properties of oils is the kinematic viscosity, which is defined as the resistance to flow at a given temperature. Notice that oils become less viscous as the temperature rises.

Oil is often used in high-speed or high-temperature applications where the lubricant is circulated to remove heat. It is, however, more difficult to seal and retain in a housing compared to grease.

Here is a list of some common oil additives:

- antioxidants
- antifoam agents
- antiwear additives
- rust inhibitors
- extreme pressure agents
- demulsifiers
- viscosity index (VI) modifiers
- corrosion inhibitors

The simplest method of oil lubrication is the oil bath method depicted in Figure 2-20. With this method, oil is picked up by rotating components such as gears and distributed within the mechanism.

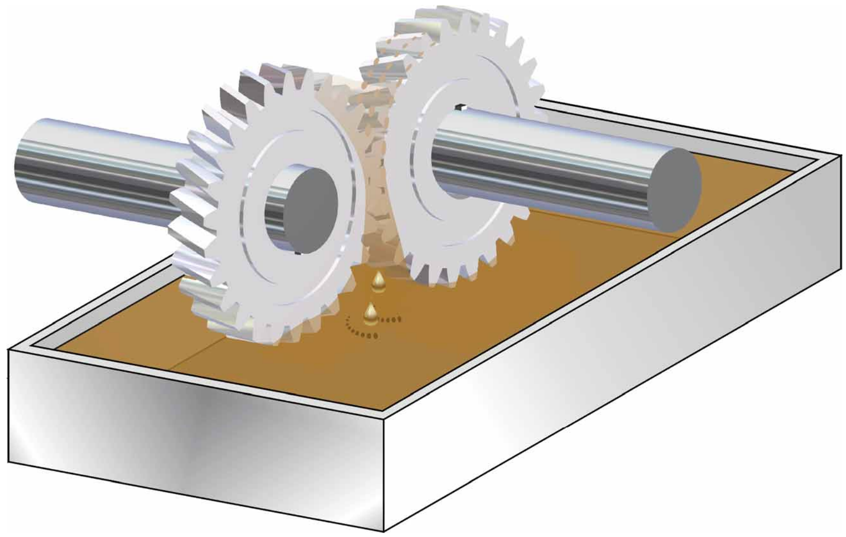


**Figure 2-20. Oil bath lubrication of gears.**

### *Greases*

Greases are semi-solid lubricants usually formed by the combination of a base oil, a thickening agent (also called "soap"), and various additives. Common thickeners used are lithium, polyurea, calcium, PTFE, and clay.

Greases are preferred to oils or other fluid lubricants when retention is problematic or when lubrication cannot be performed frequently. For example, grease is more easily retained in a bearing arrangement, particularly where shafts are inclined or vertical. It also contributes to sealing the arrangement against contaminants, moisture, or water. An excess of lubricant causes the operating temperature to rise because of the greater friction, particularly when running at high speeds.

*Generally, when lubricating bearings assemblies, the bearings should be completely filled, and the free space in the housing should be only partly filled (between 30 to 50 percent) with grease.*

The use of one grease recipe over another depends on the conditions (e.g., temperature, humidity, load, chemical environment) under which it is used. As for lubricating oil, base oil viscosity, base oil type, and additives are all important properties of the grease. However, greases have another highly important property that is not shared with oil: its consistency.

Grease consistency is its relative hardness (degree to which it resists deformation under the application of a force). The NLGI (National Lubricating Grease Institute) specifies grease consistency in terms of grades ranging from 000, the softest, to 6, the stiffest (see Table 2-1). NLGI Grades 000 to 1 are used in applications such as enclosed and open gearings, and gear drives operating at low speeds. Grades 0, 1, and 2 are used in highly loaded gearing. Grades 1 through 4 are often used in rolling contact bearings. Grade 2 grease is the most common.

**Table 2-1. NLGI grades.**

| NLGI Grade | Appearance | Food analogy |
|---|---|---|
| 000 | fluid | cooking oil |
| 00 | semi-fluid | apple sauce |
| 0 | very soft | brown mustard |
| 1 | soft | tomato paste |
| 2 | semi-firm | peanut butter |
| 3 | firm | vegetable shortening |
| 4 | very firm | frozen yogurt |
| 5 | hard | smooth pate |
| 6 | very hard | cheddar cheese |

Bearings can be greased manually using a grease gun or automatically using an automatic lubrication system that injects frequent, measured, small amounts of grease during system operation. Figure 2-21 shows an automatic grease dispenser.


**Figure 2-21. Automatic grease dispenser.**

Exercise 2-1

# Hub and Low-Speed Shaft

**EXERCISE OBJECTIVE**

When you have completed this exercise, you will be familiar with the portion of the nacelle that extracts mechanical power from the wind and transfers that power to the gearbox.

**DISCUSSION OUTLINE**

The Discussion of this exercise covers the following points:

- Blade pitch in the nacelle system
- Low-speed (main) shaft
  *Inspection of the low-speed shaft.*
- Vibration sensor
- A first round of information concerning the gearbox
  *Inside the gearbox. Shrink disk.*
- Bolt torque
  *Notes on using the torque wrench.*
- Greasing of the bearings

**DISCUSSION**

## Blade pitch in the nacelle system

As you may already have noticed, the rotor blades of the nacelle trainer turn, but they cannot be pitched. Instead, the angle to which they would be pitched is simulated and displayed on the main screen of the panel PC. The connection status of the nacelle to either of the physical hubs is presented in the SERVICE – HUB screen. By default, the hub is simulated as indicated by the dotted line in Figure 2-22. Connection of the nacelle to either physical hubs is presented in the manuals of the hubs.

> Lab-Volt's optional electrical (Model 46123) and hydraulic (Model 46124) pitch hubs are designed to demonstrate the mechanisms behind blade pitching. They can be connected via optical fiber to operate following the nacelle's instructions.

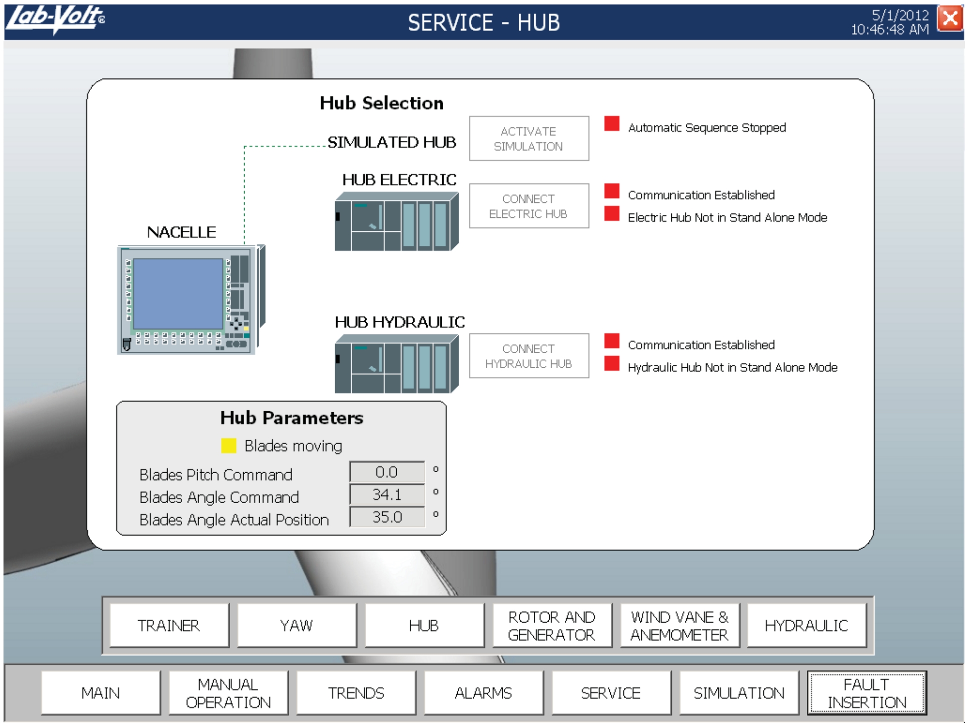



**Figure 2-22. SERVICE – HUB screen.**

## Low-speed (main) shaft

The angular speed of the shaft is read using an inductive sensor in front of which a perforated disk rotates (Figure 2-23). One pulse is sent to the controller for every low-to-high (hole-to-metal) transition, that is, ten times per shaft rotation. The controller samples the number of pulses over a few seconds and updates the number of rotations per minute (RPM) of the *Gearbox Input Speed* parameter on the main screen. For example, if the shaft has a constant speed and 400 pulses are read during a period of one minute, you should read a value of 40 RPM on the main screen.

**Figure 2-23. Inductive sensor and perforated disc.**

### *Inspection of the low-speed shaft*

The low-speed shaft of the nacelle trainer is solid. When inspecting the low-speed shaft, look for corrosion, deformation, cracks, and score marks that would indicate slippage.

## Vibration sensor

The trainer features one vibration sensor that can be installed at various places in the nacelle, provided that the cable is long enough and the assembly does not interfere with any of the rotating parts. A magnet at the base of the sensor permits the securing of the device on most metallic parts, as shown in Figure 2-24.

**Figure 2-24. Vibration sensor.**

The sensor returns a 4-20 mA signal that is proportional to the overall vibration in terms of velocity. No vibration corresponds to 4 mA and a vibration of 25.4 mm/s (1 in/s) corresponds to 20 mA.

There is more than one culprit when it comes to analyzing the sources of vibration on a wind turbine. However, the main cause of vibration on the nacelle trainer is the rotor brake disk. This is explained by the combined effect of its size, weight, and high speed of rotation. Even a small imperfection on the disk can cause perceptible vibration.

## A first round of information concerning the gearbox

### *Inside the gearbox*

Figure 2-25 is a simplified cutout view of a gearbox that could be used on the nacelle trainer. We can immediately see that there are three shafts, meaning that it is a two-stage parallel gearbox. Bearings are located on both ends of the shafts to facilitate rotation. Lip seals prevent oil or grease from leaking around the protruding shafts and contaminants from entering the housing.

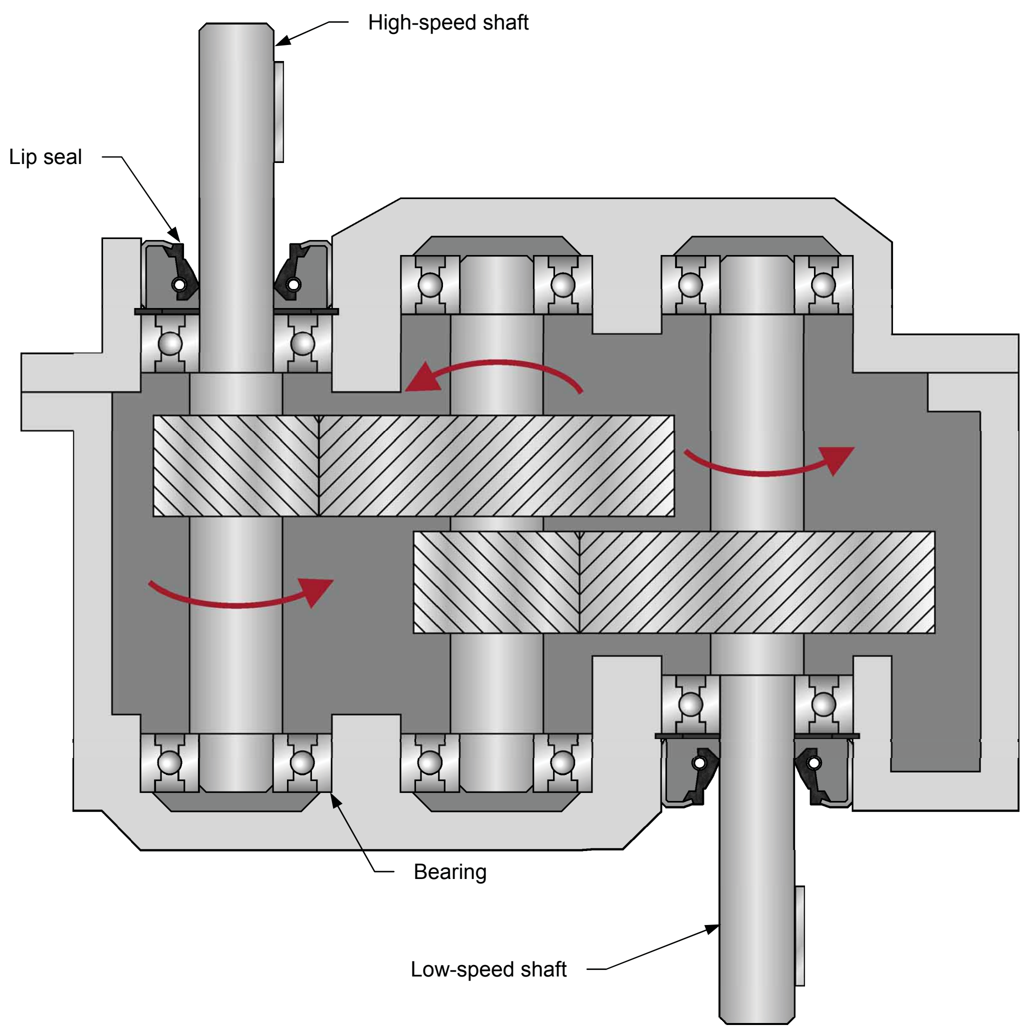



**Figure 2-25. Typical gearbox with three shafts.**

- Bearings

A bearing is a component used to reduce friction between rotating parts in a machine. Ball bearings are a type of bearing. They work under the principle of rolling motion.

The most common ball bearing is the radial ball bearing, also called deep-groove ball bearing. As Figure 2-26 shows, it consists of:

1. **Outer ring**
2. **Rolling balls**
3. **Inner ring**
4. **Raceway**
5. **Cage**

As its name implies, the radial ball bearing is mainly designed to support a radial load, but it can also support a modest axial load.

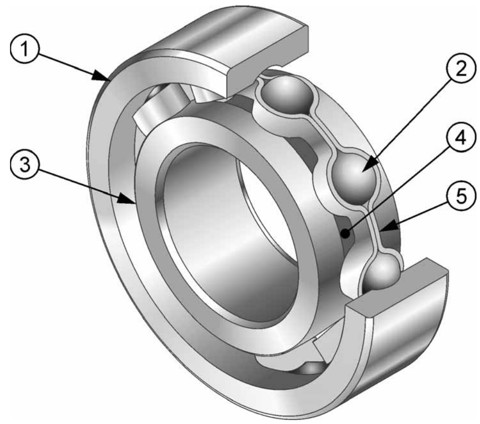



**Figure 2-26. Parts of a typical radial ball bearing.**

- Lip seals

Lip seals, also frequently called oil seals, are used to keep lubricants in, contaminants out, or both. They are installed in dynamic applications, and are commonly used to seal rotating shafts. As shown in Figure 2-27, a lip seal consists of:

1. **Case**
2. **Spring**
3. **Lip**

The lip is designed to fit around the shaft. A spring increases the pressure of the lip to improve the seal.

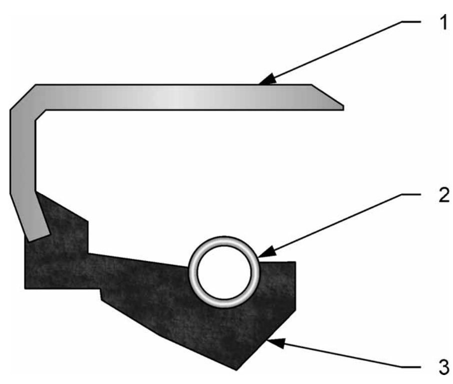



**Figure 2-27. Parts of a typical lip seal.**

Lip seals are available with one or more lips. A single-lip seal is a retention seal when the lip is facing in, and an exclusion seal when the lip is facing out. A double-lip seal performs both functions at the same time. Quadrilip seals (Figure 2-28) can also be used. The figure shows:

1. **Housing**
2. **Rubberized inner and outer diameters**
3. **Grease fillings**, to prevent dry running of the sealing lips
4. Additional **sealing lips** to protect against dirt and decoupled sealing system to prevent scoring of the shaft as a result of corrosion or dirt
5. Protected **running surface** for radial shaft sealing ring
6. **Shaft**

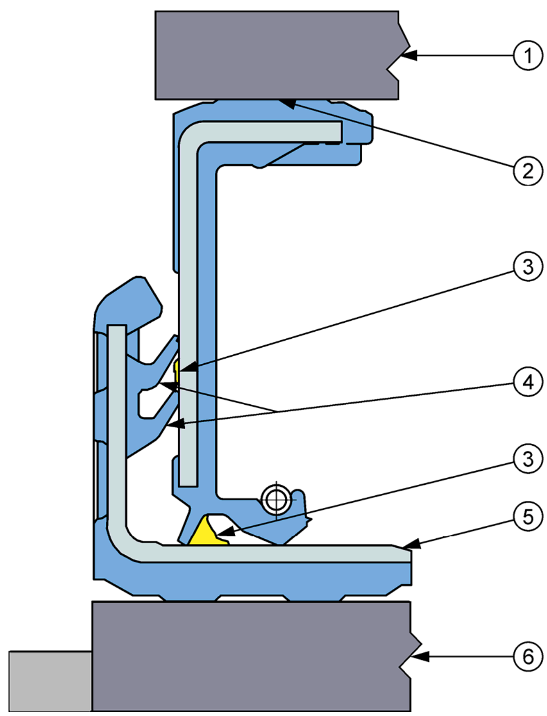



**Figure 2-28. Quadrilip seal (courtesy of Siemens).**

Figure 2-29 shows how the actual gearbox of the nacelle trainer is assembled. Two quadrilip seals are located where the low-speed shaft penetrates the gearbox and a standard radial shaft seal covers the cavity of the high-speed shaft.

*A fourth shaft is depicted since this model of gearbox can be ordered with different configurations.*

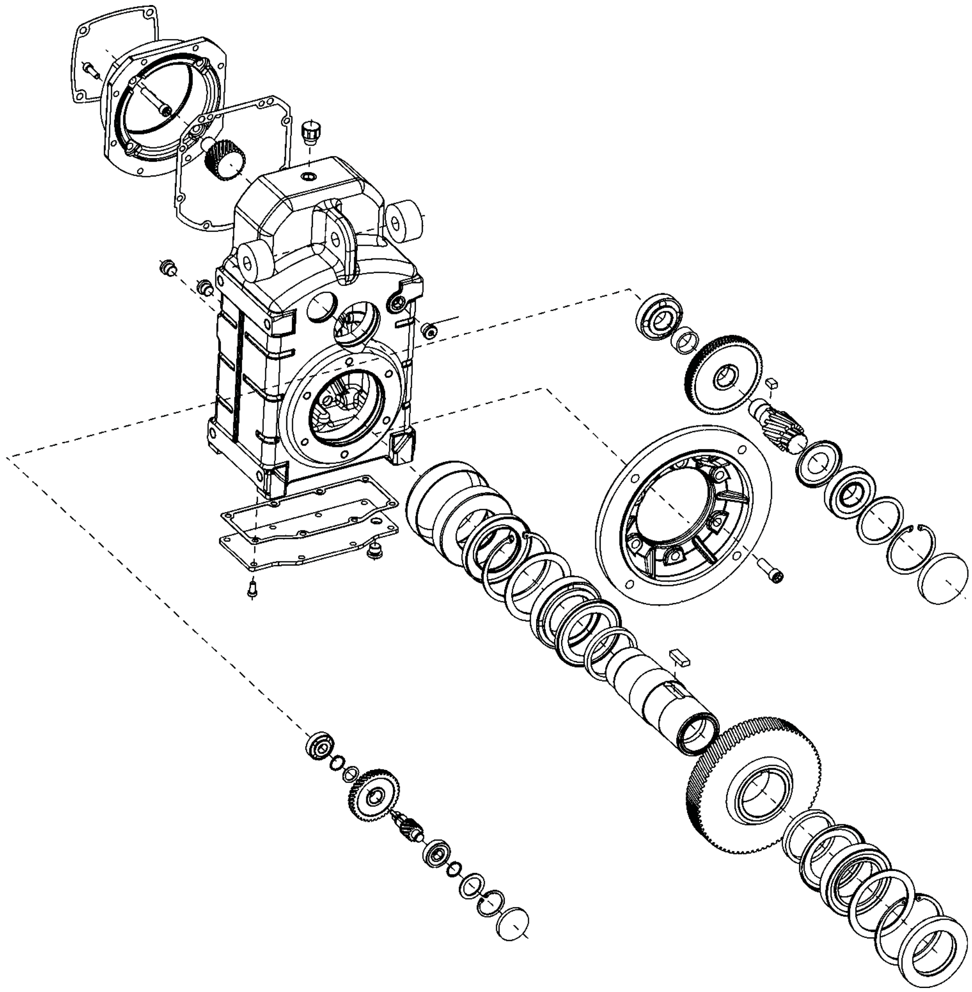


**Figure 2-29. The way the nacelle trainer gearbox is assembled (courtesy of Flender/Siemens).**

How is the gearbox coupled to the low-speed shaft? You will see in the following exercise that the low-speed shaft goes all the way through the gearbox. In fact, the low-speed shaft is dissimulated inside a hollow shaft within the gearbox. The low-speed and hollow shafts are coupled using a so-called “shrink disk”, which increases friction between the shafts.

### *Shrink disk*

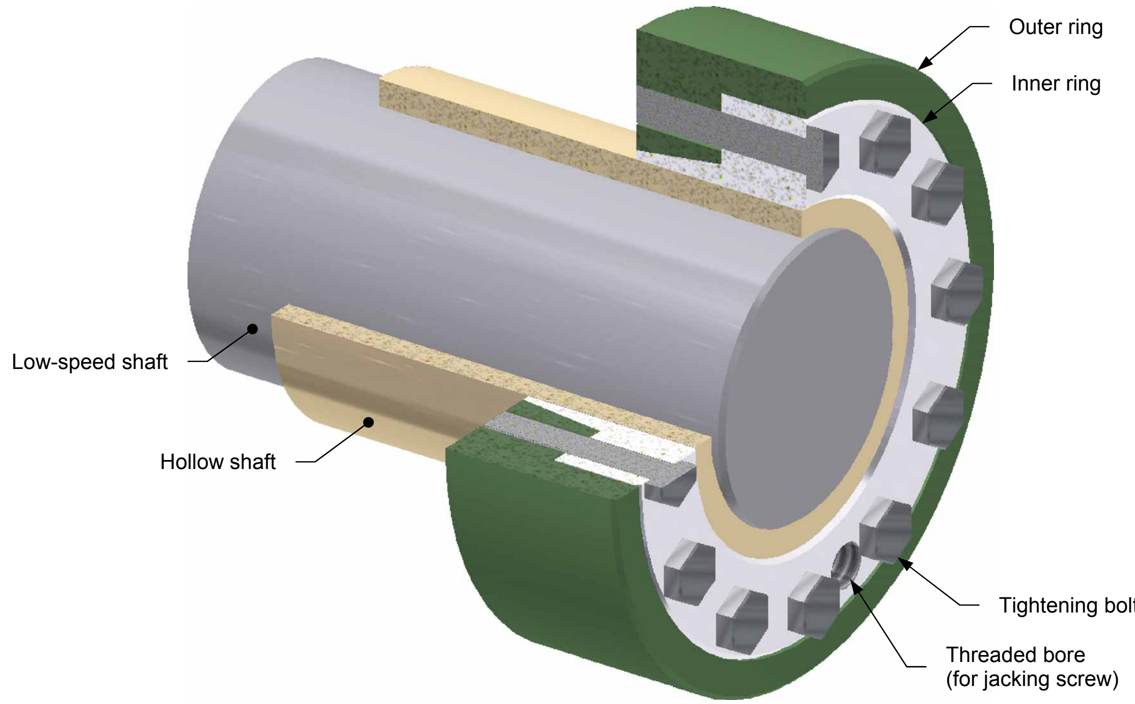



**Figure 2-30. Shrink disk (side view).**

Figure 2-30 represents a two-part shrink disk assembly around the low-speed shaft and the hollow shaft of the gearbox. When the tightening bolts are screwed, the outer ring is pulled onto the inner ring and more radial clamping force presses the hollow shaft onto the low-speed shaft. The frictional connection at the contact surface between the shaft and the hollow shaft permits torque transmission between the two shafts. To remove the shrink disk, all tightening bolts must be removed and two of these bolts must be used as jacking screws into the threaded bores.

### Bolt torque

Like on any real nacelle, bolt loosening can occur on the trainer because of vibration, resulting forces, or thermal differences.

**CAUTION**

Never operate the nacelle trainer with loosened bolts. Permanent damage to the trainer may result.

A click-type torque wrench is provided with the system (Figure 2-31), along with a 13 mm socket.

**Figure 2-31. Torque wrench and socket.**

### *Notes on using the torque wrench*

- To adjust the wrench, pull down on the collar and rotate the handle until you obtain the desired torque value, as indicated on the Metric or SAE scale, and release the collar.

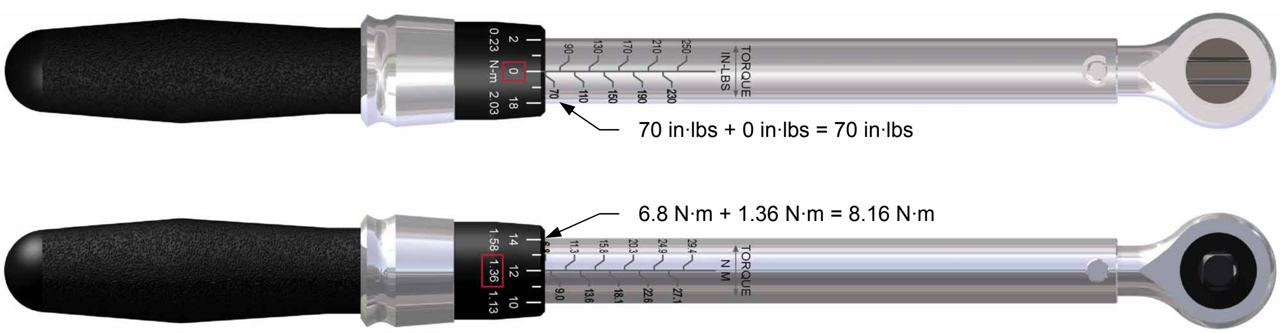



**Figure 2-32. Examples of wrench adjustments (Metric and SAE).**

> If the torque wrench can be used in reverse direction, it is because some bolts are threaded in the other direction (although not on the nacelle trainer).

- To apply torque,
  - Attach the proper socket.
  - Set the direction of operation properly.
  - Follow the recommendations of the component manufacturer as to how to torque the fasteners. Hold the handle by the grip and apply a slow and steady force.

*Usually, you will follow a pattern (criss-cross, clockwise, etc.) and apply only a small torque to the fasteners the first time. You will increase the torque during subsequent rounds until you hear and/or feel a little "click" for <u>all of the bolts during a single round</u>.*

- You should always return a torque wrench adjustment to zero after use to maintain the tool calibration.
- To tighten a fastener to a lesser torque value, loosen the fastener first before you retighten it.

- Do not use a torque wrench with excessive force (more than the rated capacity). Always use a different tool (e.g., a ratchet) for disassembly.

### Greasing of the bearings

Grease guns can have a flexible or a rigid hose.

A grease gun and a grease cartridge are provided to maintain good lubrication of the rotor and yaw bearings. The grease that was selected for the bearings of the low-speed shaft is a NLGI grade 2 lithium multipurpose grease. Grease specifications can be found in Appendix G.

## PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Accessories needed
- Basic safety procedure
- Preparation question
- Starting the trainer in automatic mode
- Starting the wind simulation
- Hub and low-speed shaft behavior
- Vibration on the low-speed shaft bearing
- Locking the rotor
- System shutdown
- Lockout/tagout
- Inspection of the low-speed shaft
- Checking bolt torque
- Examination of the gearbox
- Greasing the bearings
  *Loading the gun. Using the grease gun.*
- End of the procedure

## PROCEDURE

### Accessories needed

*For this exercise, you will need the following accessories:*

- ❑ Lockout device (hasp)
- ❑ 1 padlock and 1 tag per student
- ❑ 7 mm hex key
- ❑ Torque wrench
- ❑ 13 mm socket
- ❑ Flashlight (optional)
- ❑ Grease gun
- ❑ Grease for bearings
- ❑ Additional pillow block (optional)
- ❑ Rags (not included)

## Basic safety procedure

*Before using the training system, complete the following checklist:*

- ❑ You are wearing safety glasses and safety shoes.
- ❑ You are not wearing anything that might get caught such as a tie, jewelry, or loose clothes.
- ❑ If your hair is long, tie it out of the way.
- ❑ The working area is clean and free of oil or water.

## Preparation question


**Figure 2-33. Two coupled gears.**

**1.** As shown above, you have two coupled gears and you want the speed of the output shaft to be twice the speed of the input shaft. Compared to the second gear, how many teeth must the first gear have?

______________________________________________

**2.** What is the total gear ratio in the two-stage arrangement of Figure 2-34?

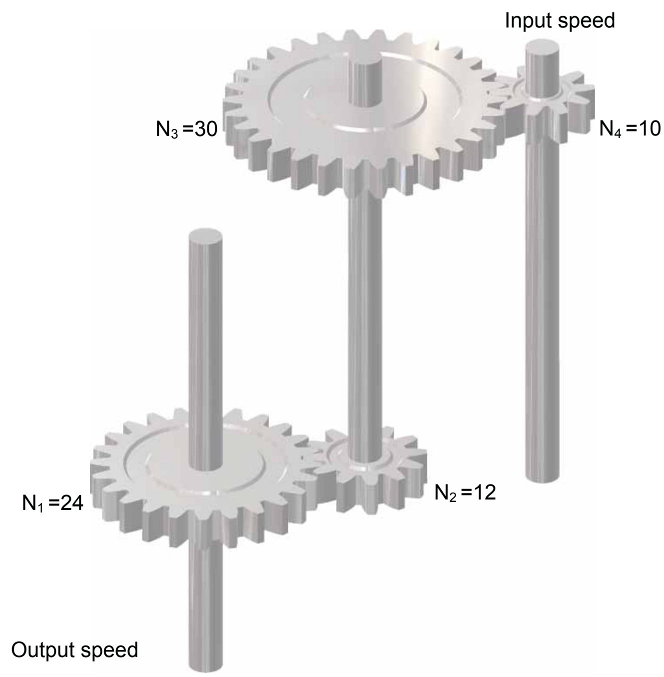



**Figure 2-34. Two stages of reduction.**

---

## Starting the trainer in automatic mode

**3.** Make sure the main switch is off and everything is secure inside and around the nacelle.

**4.** Open the safety panels and position the vibration sensor on the first pillow block (Figure 2-35).

**CAUTION**

Never let the vibration sensor cable run near moving parts as it could get stuck and become damaged.

**Figure 2-35. Vibration sensor on the pillow block.**

5. Close all safety panels.

6. Notify all the people working around the nacelle that the system is about to be energized and ask your instructor for permission to power the nacelle training system.

7. Turn on the main power switch. Wait for the panel PC to boot and log into Windows. The HMI should start automatically.

8. Press the green (physical) start button under the main switch to start the system.

9. Press *Start Trainer* in the HMI MAIN screen.

10. If the *ALARMS* button is flashing red at this point, press it. In the opening ALARMS screen, acknowledge each current alarm. Next, press *RESET ALARMS*, if necessary.

## Starting the wind simulation

**11.** Program the following steps in the WIND SIMULATION screen:

**Table 2-2. Wind steps.**

| | Step #1 | Step #2 | Step #3 |
|---|---|---|---|
| Duration (s) | 50 | 50 | 50 |
| Wind Direction (°) | 0 | 45 | 90 |
| Wind Speed [m/s (mph)] | 10 (22.4) | 12 (26.8) | 18 (40.3) |

**12.** Enable all three steps and start the wind simulation.

**13.** Press *START AUTOMATIC* in the main screen to change *Operation Status* to *Automatic*.

## Hub and low-speed shaft behavior

**14.** Note the blade pitch angle at the end of each step.

**Table 2-3. Blade pitch angle for different wind speeds.**

| Step | Wind Speed (m/s [mph]) | Blade angle command (°) | Blade angle actual position (°) | Gearbox input speed (RPM) |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |

**15.** What can you tell about the relationship between the blade angle and wind speed?

__________________________________________________________________

__________________________________________________________________

**16.** Show where the "Gearbox Input Speed" sensor is located in the following picture.

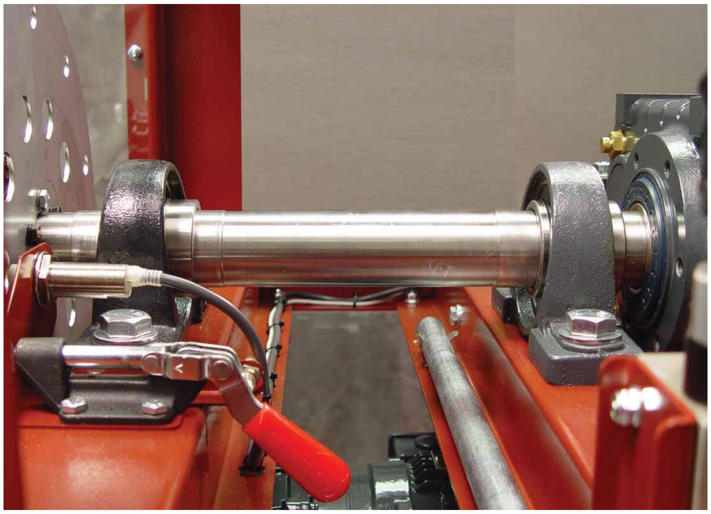


**Figure 2-36. Rotor Shaft.**

**17.** (Optional) To your knowledge, what type of sensor is it?

______________________________________________

**18.** Does the speed of the low-speed shaft vary significantly during energy production? Why does this occur?

______________________________________________

______________________________________________

## Vibration on the low-speed shaft bearing

**19.** Open the TRENDS screen and select *ROTOR VIBRATION*.

**20.** Observe the evolution of the curve. Is vibration constant during active control? If not, when does the vibration level reach a peak?

______________________________________________

______________________________________________

**21.** Stop the wind simulation

## Locking the rotor

**22.** Return to the MAIN screen and press *STOP*. Then, press MANUAL to change *Operation Status* to *Manual Mode*.

**23.** Press *MANUAL OPERATION* at the bottom to navigate to the MANUAL screen.

**24.** If the parking brake is still on, press *RELEASE* on the Rotor panel to release it.

**25.** Use the *JOG* button on the Rotor panel to rotate the low-speed shaft at a reduced speed. Is there something unusual like a sound or crookedness as the shaft rotates?

❑ Yes ❑ No

**26.** Use the *JOG* button again to align a hole in the perforated rotor disk with the rotor locking pin. Once aligned, open the nacelle top safety panel (front side) and engage the locking pin using the hand lever.

**27.** Close the nacelle safety panels.

## System shutdown

**28.** Exit the HMI by pressing *X* on the top-right corner of the screen.

**29.** Press the Windows *Start* button, select *Shut Down*, and press *OK*. Wait for the system to turn off.

*You may have to reset alarms before exiting the software.*

**30.** Use the main power switch to turn all system power off.

## Lockout/tagout

*For the inspection to follow, the nacelle needs to be secured first.*

**31.** Install the lockout hasp in the main switch. Next, install the student padlocks and tags in the hasp.

**32.** Try to turn on the main switch to verify that the system really is electrically isolated. Press the start push-button to test whether the system can be energized.

**33.** Open the front safety panels.

**34.** Depressurize the accumulator of the hydraulic system by lifting the lever of valve MV1. Return the lever to the original position once the accumulator is depressurized (i.e., after approximately ten seconds).

*At this point, the system can be considered secure.*

## Inspection of the low-speed shaft

**35.** Take a look at the low-speed shaft. Does it show evident damage, such as corrosion or cracks?

❑ Yes ❑ No

**36.** Remove the gearbox shrink disk cover using the 7 mm hex key (Figure 2-37). Also remove the o-ring under the cover so that it does not fall inadvertently.

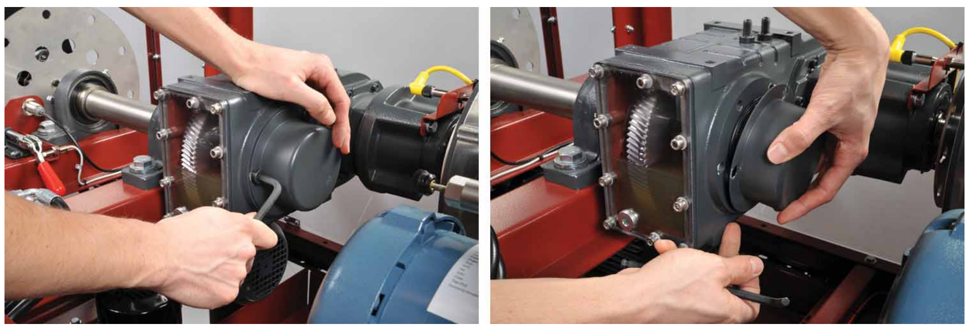


**Figure 2-37. Removing the shrink disk cover.**

**37.** Do you see anything unusual such as score marks between the locking ring and the shaft which would indicate slippage?

❑ Yes ❑ No

If so, note your observations below.

______________________________________________

______________________________________________

## Checking bolt torque

**38.** Take the 3/8" torque wrench and the 13 mm socket.

**39.** Adjust the torque wrench to 28.2 N·m (250 lbs·in) in the clockwise direction.

**40.** Verify that each bolt is adjusted to at least 28.2 N·m (250 lbs·in) (Figure 2-38). Start with the top bolt and proceed clockwise. Go slowly so you can feel the small click (or shock) when the wrench reaches the given torque. Be careful: if you miss the click, you will over-torque the bolt!

*Oftentimes, manufacturers ask to tighten bolts placed in circle in a crisscross pattern. In our case, the gearbox manufacturer specifies a circular pattern.*

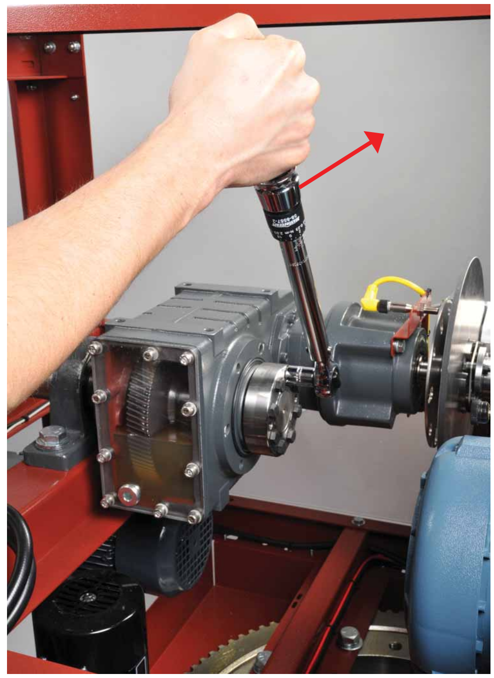


**Figure 2-38. Verifying the torque of a bolt.**

**41.** Return the torque wrench adjustment to zero.

**42.** Reinstall the o-ring and shrink disk cover.

## Examination of the gearbox

**43.** Look inside the gearbox. How many gears do you see?

______________________________

**44.** Which gear is the biggest? Explain why it is this way.

Refer to the preparation question

______________________________

______________________________

______________________________

**45.** What type of gears do you see? Spur, helical, or double helical?

_______________________________________________

## Greasing the bearings

*The grease gun model can vary. If you are using a different model, refer to the manufacturer's directions.*

### *Loading the gun*

**46.** Go to Appendix G and write down what grease is recommended for the bearings of the low-speed shaft.

_______________________________________________

**47.** Take the grease gun. Pull back the rod handle and lock it (Figure 2-39).

*There can be a mess if you unscrew the barrel and the rod is not pulled and locked!*

**Figure 2-39. Locking the rod handle.**

**48.** Unscrew the gun head from the barrel (Figure 2-40).

**Figure 2-40. Opening the grease gun.**

**49.** The cartridge can be removed to verify that the grease meets the bearing requirements. If you need to add a new cartridge:

1. Remove the plastic cap (Figure 2-41).

**Figure 2-41. Removing the plastic cap.**

2. Insert the new cartridge, open end first, into the barrel. Push the cartridge until the pull-tab seal is level with the barrel rim (Figure 2-42).

**Figure 2-42. Inserting a new grease cartridge.**

3. Remove the seal (Figure 2-43).

**Figure 2-43. Removing the seal.**

4. Screw the gun head back into place.

5. Unlock the rod handle and push it back to exert pressure on the grease and depress the air bleeder valve to expel air.

6. Pump the lever until grease flows out (Figure 2-44).

**Figure 2-44. Grease flowing out of the gun.**

### *Using the grease gun*

**50.** Wipe the first pillow block grease fitting with a clean rag to prevent dirt from entering the bearing. Insert your loaded gun coupler into the fitting (Figure 2-45).

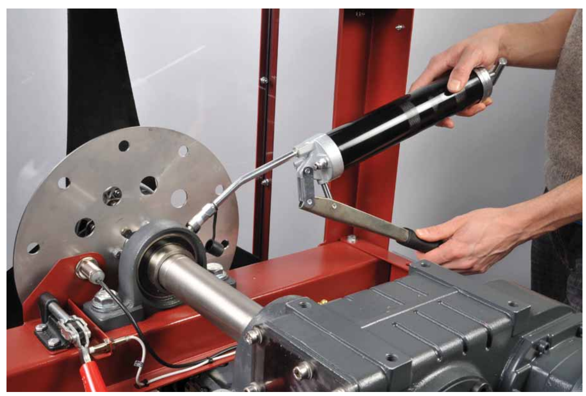


**Figure 2-45. Inserting grease gun into the pillow block nipple.**

**51.** Depending on the choice of your instructor, pump the gun once in this pillow block or in the smaller pillow block that is part of the accessory kit.

**52.** Clean the grease fitting with a rag to prevent dust from sticking to the grease left on the fitting.

## End of the procedure

**53.** Disengage the rotor locking pin.

**54.** Close the safety panels.

**55.** Clean the area.

**56.** Ask everyone to remove their individual padlock and tag. Next, remove the hasp from the main switch.

## CONCLUSION

In this exercise, you became more familiar with the hub and low-speed shaft portions of the nacelle. First, you examined how the blades are pitched during normal operation and observed the vibration level. Then, you performed a lock-out/tagout procedure to inspect the low-speed shaft, verify bolt torque, and grease some bearings.

## REVIEW QUESTIONS

1. Which items do you need to lubricate the low-speed shaft bearings of the nacelle trainer?

   ______________________________

   ______________________________

2. What portion of a real nacelle aerodynamically regulates the speed of the low-speed shaft?

   ______________________________

3. Which tool is used to measure the force applied while fastening the bolts?

   ______________________________

4. What can score marks indicate on a low-speed shaft?

   ______________________________

5. Which type of gears does the nacelle trainer gearbox contain?

   ______________________________

# Exercise 2-2

## Gearbox, Coupling, and Alignment

**EXERCISE OBJECTIVE**

When you have completed this exercise, you will be familiar with the high-speed part of the drive train system between the gearbox and the generator. More specifically, you will check gearbox temperature at rest and during operation, analyze vibration on the gearbox, change gearbox oil, and align the shafts.

**DISCUSSION OUTLINE**

The Discussion of this exercise covers the following points:

- More information about the gearbox
  *Gear ratio. Oil. Temperature sensor. Fastening.*
- High-speed shaft
  *Coupling and alignment with the generator. Alignment procedure.*

**DISCUSSION**

### More information about the gearbox

#### *Gear ratio*

You already know (as the names indicate) that the high-speed shaft runs faster than the low-speed shaft. In fact, the gearbox provides a ratio of 38.45 between these rotational speeds. Therefore, a low-speed shaft rotating at 47 RPM will drive the high-speed shaft at 1800 RPM.

An inductive sensor similar to that on the low-speed side is also located on the high-speed side and updates the number of rotations per minute (RPM) of the *Gearbox Output Speed* parameter on the main screen. Knowing these two angular speed values (displayed on the interface screen), the controller can verify that the speed ratio remains constant (i.e., at 38.45).

#### *Oil*

The trainer gearbox comes pre-filled with about 1.3 L (0.34 gal) of synthetic oil. A normal oil level should be around the middle of the see-through cover, like on Figure 2-46. Do not underfill or overfill the gearbox.

*Refer to Appendix G for oil specifications. Two types of oil (synthetic and mineral) are recommended. Be sure to use one or the other, but not both at the same time.*

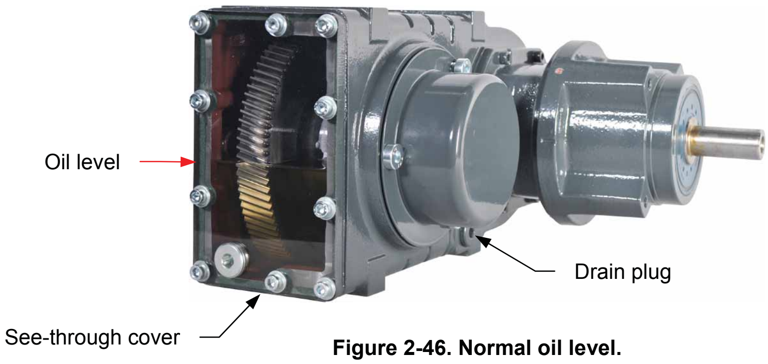



**Figure 2-46. Normal oil level.**

As with any oil, you may have to change it after a certain number of hours of operation if it changes color or appearance, or just for the sake of practicing the procedure since it is part of a training system.

*You may be asked to reuse the same oil or to use new oil, depending on your instructor's choice.*

**Figure 2-47. Drain plug (left) and magnetic drain plug (right).**

Take note that the drain plug of this gearbox may feature a magnet (as shown in Figure 2-47) to collect metallic residues so that they don't circulate with the oil and cause damage to the gears. Should you change the oil, be sure to clean the plug to remove these residues. Also, make sure that you dispose of the used oil in a proper manner, in accordance with local regulations. This principle applies here in the classroom as well as in real life.

Beside the drain plug, other openings in the housing are:

- A breather valve to equilibrate air pressure without letting dirt in. This is also the oil filling opening.
- A sight glass located just above normal oil level.

*It is pure luxury to have both a see-through cover and a sight glass to check the oil level. In many cases, you will only find a plug that you need to remove in order to evaluate the oil level.*

### *Temperature sensor*

A thermocouple is attached to the gearbox enclosure to provide feedback regarding the actual gearbox temperature at any time to maintain the system in reasonable conditions of operation. High oil temperature can cause damage just as serious as oil contamination does.

Gearbox oil temperature elevation during operation is a common phenomenon. When surface cooling is not sufficient, an additional cooling system might be required.

An offset can be added to the gearbox and generator temperature values through the Service screen (Figure 2-48). Unless otherwise specified, you should always leave these values at zero.

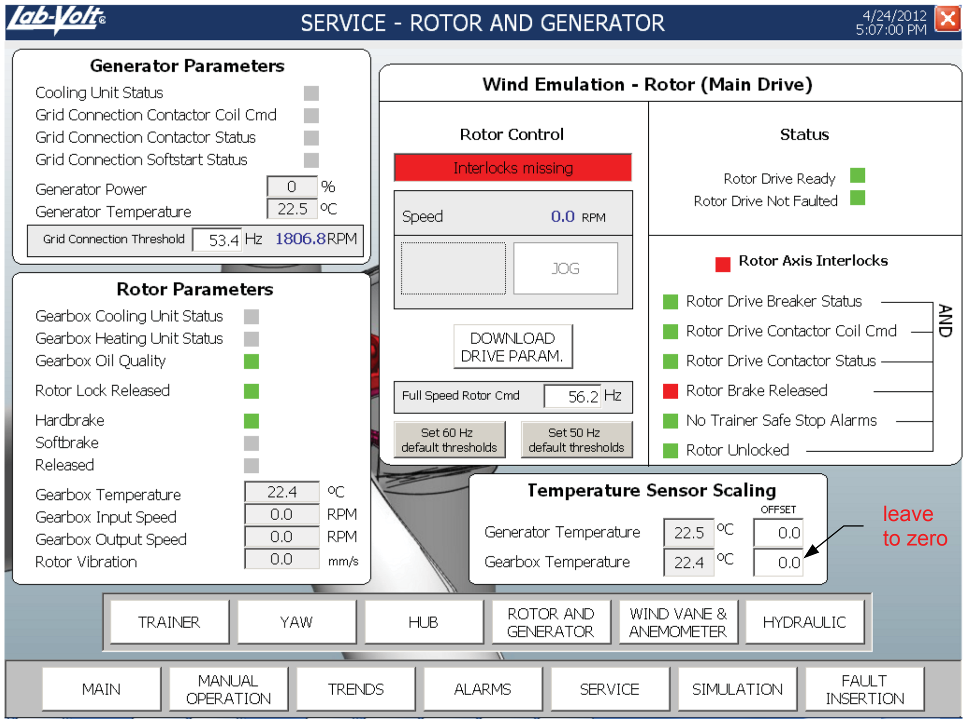



**Figure 2-48. Temperature offset on the Service screen.**

## *Fastening*

The gearbox of your training system is shaft mounted. It is maintained in position by two elements: the low-speed shaft and the "torque arm bolt" (Figure 2-49). The low-speed shaft maintains the gearbox along its longitudinal axis while the torque arm bolt secures the gearbox in the remaining degree of freedom. The height of the gearbox is adjustable through the torque arm bolt.

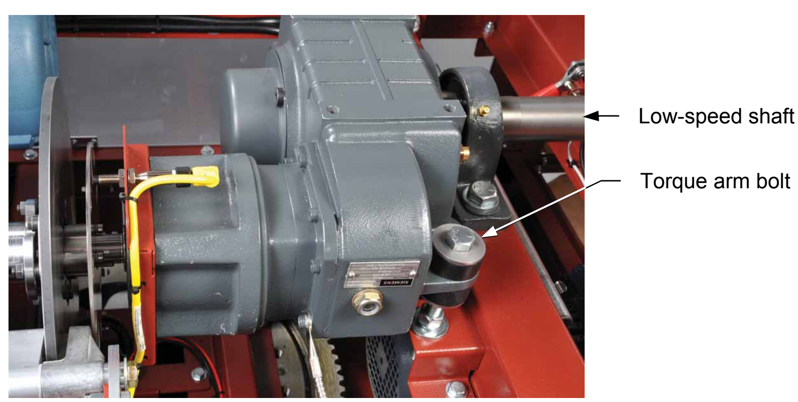



**Figure 2-49. The two gearbox anchors.**

## High-speed shaft

The high-speed shaft of the trainer is solid, just like the low-speed shaft. In fact, the only hollow shaft on the system is the shaft inside the gearbox through which the low-speed shaft passes and to which it is fastened using a shrink disk (the same shrink disk that you accessed in Ex. 2-1).

### *Coupling and alignment with the generator*

The nacelle trainer features the double disk coupling presented in Figure 2-50. It permits a maximum angular misalignment of 1.4° (0.7° per disc) when no radial or axial misalignment is present. The manufacturer table of tolerances is given in Appendix G for reference.

**Figure 2-50. Disk brake and coupling.**

### *Alignment procedure*

The nacelle training system comes with a stylus indicator alignment kit (Figure 2-51). The procedure on how to align shafts using this kit is detailed in the exercise procedure to follow.

**Figure 2-51. Stylus indicator alignment kit.**

The arrangement of the high-speed shaft and disk brake does not allow for full rotation of the alignment kit. However, half-turn rotation permits sufficient accuracy for the application.

**PROCEDURE OUTLINE**

The Procedure is divided into the following sections:

- Accessories needed
- Basic safety procedure
- Preparation question
- Setting up the nacelle
  *Checking gearbox oil level, quality, and possible spill.*
- Starting the trainer in automatic mode
- Gearbox temperature at rest
- Starting the wind simulation
  *Vibration on the nacelle. Gearbox temperature during active control.*
- System shutdown
- Lockout/tagout
- Gearbox oil change
  *Filling with some new, clean oil.*
- High-speed shaft and generator alignment
- Result of the alignment
- End of the procedure

**PROCEDURE**

## Accessories needed

*For this exercise, you will need the following accessories:*

- ❑ Lockout device (hasp)
- ❑ One padlock and one tag per student
- ❑ 8 mm hex key (gearbox drain plug)
- ❑ 17 mm wrench (breather valve plug)
- ❑ Black plastic drain pan
- ❑ Galvanized steel funnel with strainer
- ❑ Rags (not included)
- ❑ Alignment kit
- ❑ Shims
- ❑ Two 13 mm wrenches (high-speed inductive sensor)
- ❑ Two 9/16” wrenches (alignment kit)
- ❑ Two 3/4” wrenches (torque arm bolt, stylus points, and sight glass plug)
- ❑ Two 1/2" wrenches (generator foot bolts)[2]

## Basic safety procedure

*Before using the training system, complete the following checklist:*

- ❑ You are wearing safety glasses and safety shoes.
- ❑ You are not wearing anything that might get caught such as a tie, jewelry, or loose clothes.

[2] It is easier to use a wrench and a ratchet (not included) for the bolts of the generator.

- ❑ If your hair is long, tie it out of the way.
- ❑ The working area is clean and free of oil or water.

## Preparation question

**1.** Where is the gearbox thermocouple located?

________________________________________

________________________________________

## Setting up the nacelle

**2.** Make sure the main switch is off and everything is secure inside and around the nacelle.

**3.** Open the safety panels and position the vibration sensor on the gearbox (Figure 2-52).

**CAUTION**

Never let the vibration sensor cable run near moving parts as it could get stuck and become damaged.

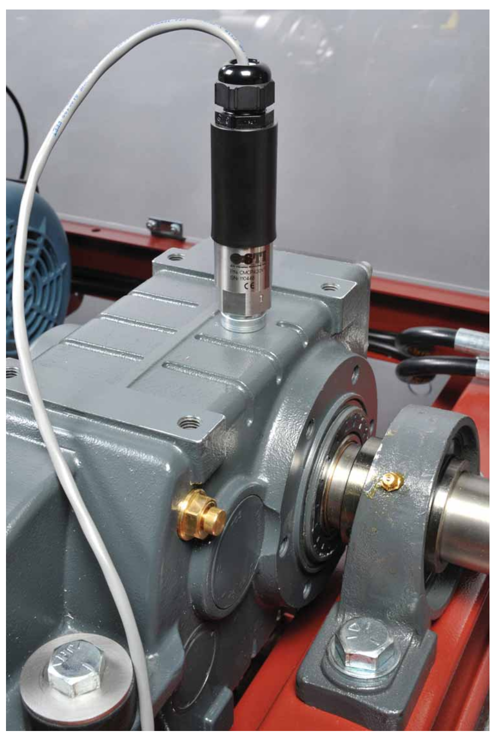


**Figure 2-52. Vibration sensor on the gearbox.**

### *Checking gearbox oil level, quality, and possible spill*

**4.** Is the gearbox oil level similar to what you see in Figure 2-46?

❑ Yes ❑ No

If not, ask your instructor if you should add/remove oil before starting the nacelle trainer.

**5.** Is the oil dark or black, indicating thermal decomposition or contamination?

❑ Yes ❑ No

If yes, ask your instructor if you should change the oil before starting the nacelle trainer.

**6.** Do you observe any unusual oil leak in, around, or under the trainer?

❑ Yes ❑ No

**7.** If there is a leak, what is the possible origin of the leak? Do you suspect a particular seal?

______________________________________________

______________________________________________

______________________________________________

**8.** If necessary, clean any spilled oil according to the procedure established in your classroom.

**9.** Close all safety panels.

## Starting the trainer in automatic mode

**10.** Notify all the people working around the nacelle that the system is about to be energized and ask your instructor for permission to power the nacelle training system.

**11.** Turn on the main power switch. Wait for the panel PC to boot and log into Windows. The HMI should start automatically.

**12.** Press the green (physical) start button under the main switch to start the system.

**13.** Press *Start Trainer* in the HMI MAIN screen.

**14.** If the *ALARMS* button is flashing red at this point, press it. In the opening ALARMS screen, acknowledge each current alarm. Next, press *RESET ALARMS*, if necessary.

### Gearbox temperature at rest

**15.** What is the gearbox temperature at this time, as indicated on the main screen?

____________________________________________

### Starting the wind simulation

**16.** Program the following steps in the WIND SIMULATION screen:

**Table 2-4. Wind steps.**

| | Step #1 | Step #2 |
|---|---|---|
| Duration (s) | 60 | 60 |
| Wind Direction (°) | 0 | 10 |
| Wind Speed [m/s (mph)] | 10 (22.4) | 12 (26.8) |

**17.** Enable the two steps and start the wind simulation.

**18.** Press *START AUTOMATIC* in the main screen to change Operation Status to *Automatic*.

#### *Vibration on the nacelle*

**19.** Open the TRENDS screen and select *ROTOR VIBRATION*.

*At this point, it is quite possible that the vibration level triggers a warning (at 15 mm/s [0.6 in/s]) or an alarm (at 24 mm/s [0.8 in/s]) on the trainer, stopping operation altogether. If this happens, continue the procedure even though the trainer is stopped. High vibration level might be another good reason to perform the alignment check that is coming.*

**20.** Observe the evolution of the curve. What is the maximum vibration level that you can observe?

____________________________________________

**21.** Is vibration constant during active control? If not, when is it higher?

_______________________________________________

_______________________________________________

***Gearbox temperature during active control***

**22.** What is the temperature inside the gearbox at this time?

_______________________________________________

**23.** How does this value compare to temperature obtained at step 15? What does it mean?

_______________________________________________

_______________________________________________

## System shutdown

**24.** Stop automatic control and the wind simulation.

**25.** Exit the HMI by pressing *X* on the top-right corner of the screen.

**26.** Press the Windows *Start* button, select *Shut Down*, and press *OK*. Wait for the system to turn off.

*You may have to reset alarms before exiting the software.*

**27.** Use the main power switch to turn all system power off.

## Lockout/tagout

*For the operations to follow, the nacelle needs to be secured first.*

**28.** Install the lockout hasp in the main switch. Next, install the student padlocks and tags in the hasp.

**29.** Try to turn on the main switch to verify that the system is electrically isolated. Press the start push-button to test whether the system can be energized.

*At this point, the system can be considered secure.*

## Gearbox oil change

*Draining the old oil*

**30.** Open the safety panels.

**31.** Remove the (brass) pressure breather valve using the 17 mm wrench (Figure 2-53) to facilitate draining and pour new oil later.

The pressure breather valve allows the gearbox to compensate for the change of oil volume by letting some air in or out while keeping dirt particles out.

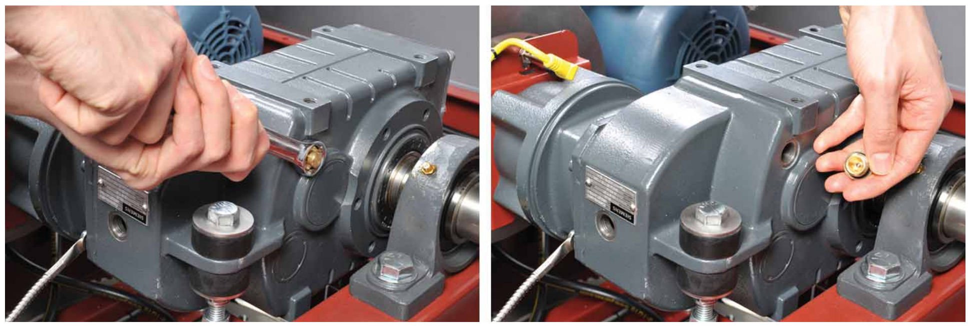


**Figure 2-53. Opening the pressure breather valve.**

**32.** Position a plastic drain pan under the gearbox from the lower safety panel.

*Use a clean pan if you plan on reusing the oil.*

**33.** Take the 8 mm hex key and remove the drain plug, as shown in Figure 2-54.

*The first time that you unscrew the drain plug, you may need to remove some paint and apply more force.*

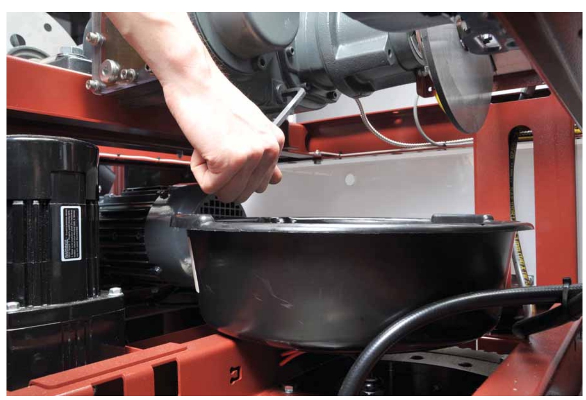


**Figure 2-54. Removing the drain plug.**

**34.** Let the "old" oil drain completely. This should take a couple of minutes. You may want to start the *High-speed shaft and generator alignment* procedure now while you are waiting for the oil to drain.

*If you change synthetic for mineral oil or vice versa, it is important keep the volume of old oil to a minimum to avoid mixing different types of oil.*

*Although it is not necessary here, keep in mind that it is sometimes required to flush the oil completely more than once when two oil types are highly incompatible.*

**35.** Clean the drain plug, check the sealing element, and screw the plug back into place.

**36.** Either keep the “old” oil to reuse it later, or dispose of it in a manner discussed with your instructor.

### *Filling with some new, clean oil*

**37.** Take the 3/4” wrench and remove the sight glass plug (Figure 2-55).

The sight glass plug is located just above the normal oil level.

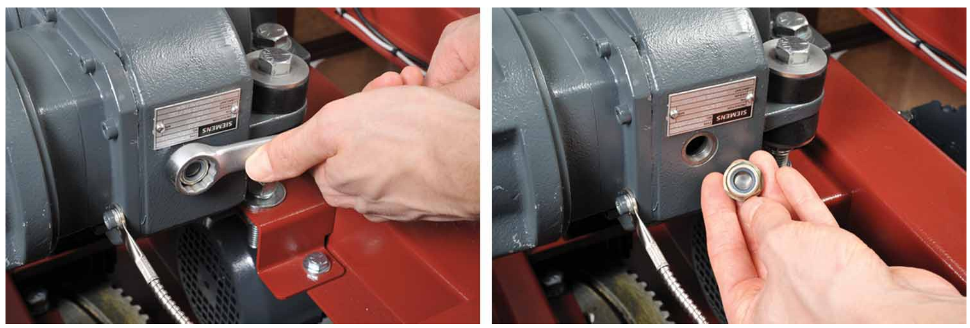


**Figure 2-55. Removing the sight glass plug.**

**38.** Using the metal funnel, pour new (or “new”) oil into the gearbox through the breather valve opening. If you do not reuse the same oil, you will need approximately 1.3 L (0.34 gal) of oil. A filled gearbox will have oil up to the bottom of the sight glass plug.

*The strainer inside the metal funnel prevents residues from entering the gearbox.*

**Figure 2-56. Pouring new oil into the gearbox.**

**39.** Verify that there is no oil leak around the drain plug.

**40.** Check the condition of the pressure breather valve and sight glass plug. Change their sealing element if necessary, and screw them back into place.

## High-speed shaft and generator alignment

**41.** Prepare your tools for the alignment procedure.

**42.** (Optional – necessitates a feeler gauge) Check for soft foot and place shims under the faulty foot if necessary.

**43.** Uninstall the inductive sensor (Figure 2-57) using a pair of 13 mm wrenches.

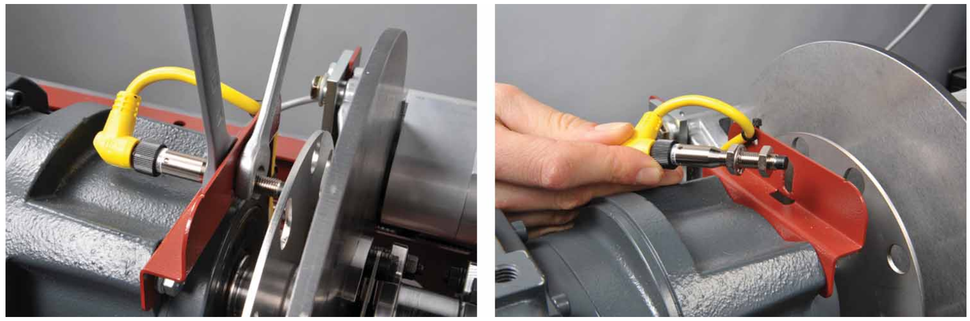


**Figure 2-57. Removing the sensor on the disk brake.**

**44.** Release the parking brake manually. To do so, screw the knob of valve SV6 completely and then rotate the knob of valve SV4 by a quarter turn, as shown in Figure 2-58.

*A minimum pressure of 51.7 bar (750 psi) is required at port* ***GB2*** *to release the brake. Use the hand pump to increase pressure if necessary. Figure 3-51 in Unit 3 shows how to use the hand pump.*

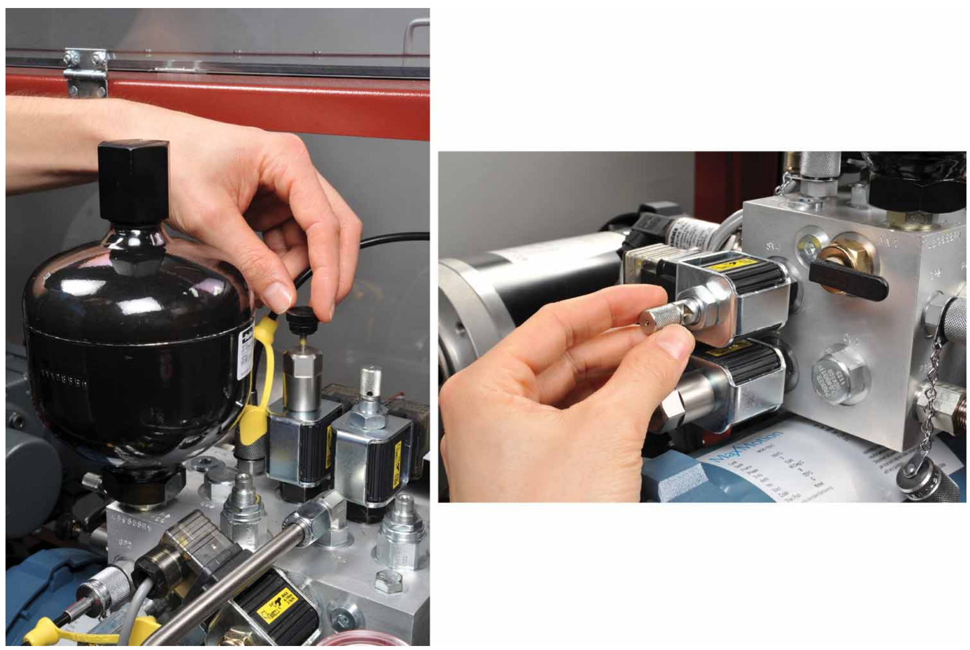
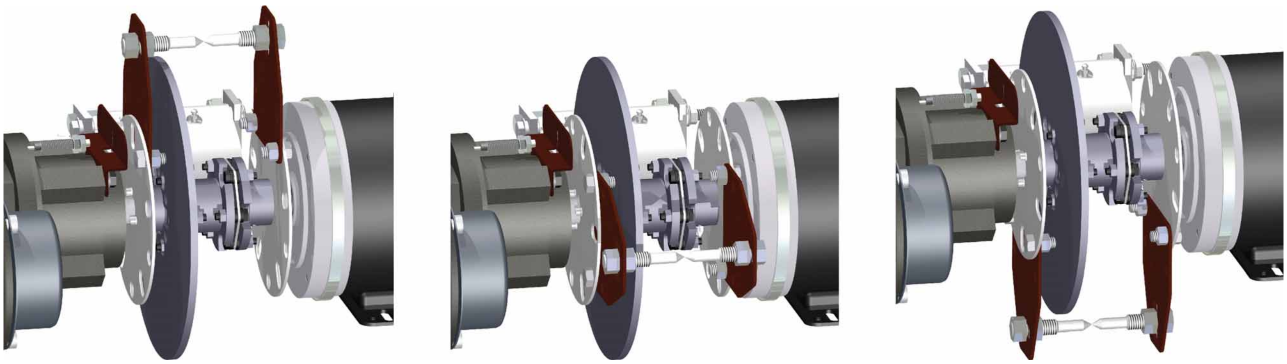


**Figure 2-58. Releasing the parking brake manually.**

**45.** Install one part of the kit on either side of the coupling as shown in Figure 2-59a. Insert the bolts in the bottom holes of the red bracket and use the 9/16” wrenches to secure them.



(a) 0 degrees (b) 90 degrees (c) 180 degrees

**Figure 2-59. Alignment kit positions.**

**46.** One stylus can be moved vertically and the other one horizontally on the bracket. Align the styluses in both directions, and use the screws to move the styluses closer or farther apart until the points almost touch in the 0° position.

**47.** (Vertical plane angular misalignment) Rotate the shaft between the 0° and 180° positions. If the points move closer or farther apart (ignore vertical travel for now), this means there is angular misalignment (Figure 2-60). Place or remove shims under the front or back of the generator to reduce angular displacement by about half of the maximum separation distance.

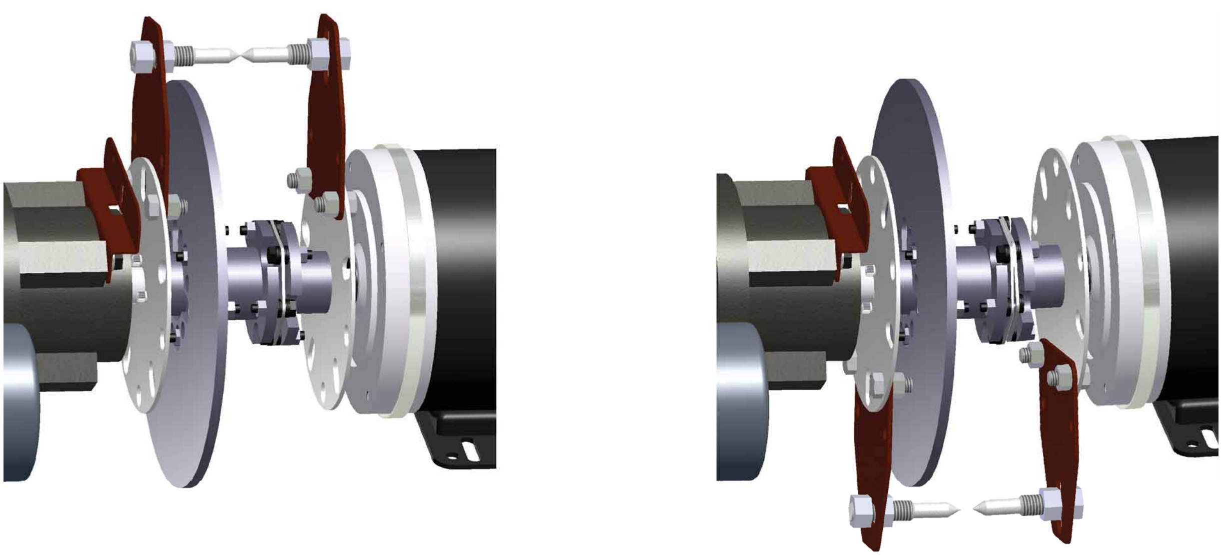


**Figure 2-60. Angular misalignment.**

**48.** Reposition the stylus points when the shaft is at the 0° position. Rotate the shafts and verify that the distance between styluses remains the same (ignore vertical travels for now). Repeat the previous step if necessary.

**49.** (Vertical plane parallel misalignment) Rotate the shaft between the 0° and 180° positions again. This time, correct the vertical offset (Figure 2-61) by moving the torque arm bolt up or down (Figure 2-62) or by placing shims under all four feet of the generator for an adjustment of about half of the observed offset.

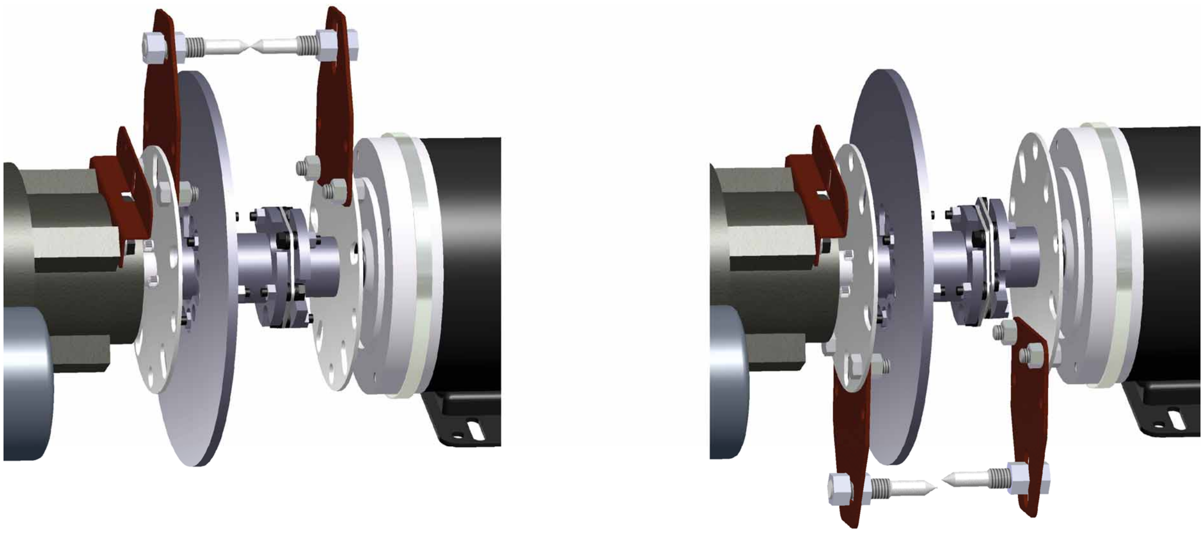
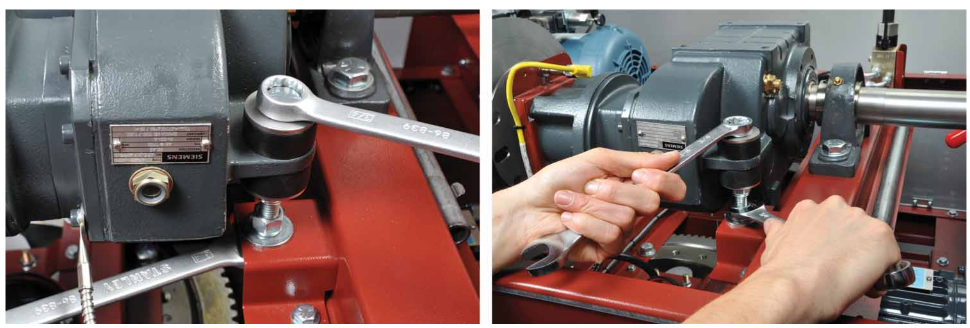


**Figure 2-61. Vertical offset.**

*Use two 3/4" wrenches to adjust the torque arm bolt height (Figure 2-62).*



(a) bottom nut rotation (bolt remains static) | (b) second nut rotation (bolt remains static)

**Figure 2-62. Moving the torque arm bolt by rotating the two lower nuts.**

**CAUTION**

Do not rotate the torque arm bolt or the top nut. Squeezing the black rubber washers may damage them. Only rotate the bottom two nuts and hold the bolt in place if necessary to modify the gearbox height. Do not forget to retighten the bottom nuts to avoid damage next time the trainer is started.

**50.** Reposition the stylus points when the shaft is at the 0° position. Rotate the shafts and verify that the vertical distance remains minimal. Repeat the previous step if necessary. If the points move closer or farther apart, this is a sign of angular misalignment and you may need to repeat step 47.

**51.** (Horizontal plane misalignment) Rotate the shaft between the 0° and 90° positions. Correct for any angular offset (Figure 2-63) by loosening the generator bolts and slowly moving the generator sideways. Retighten the bolts.

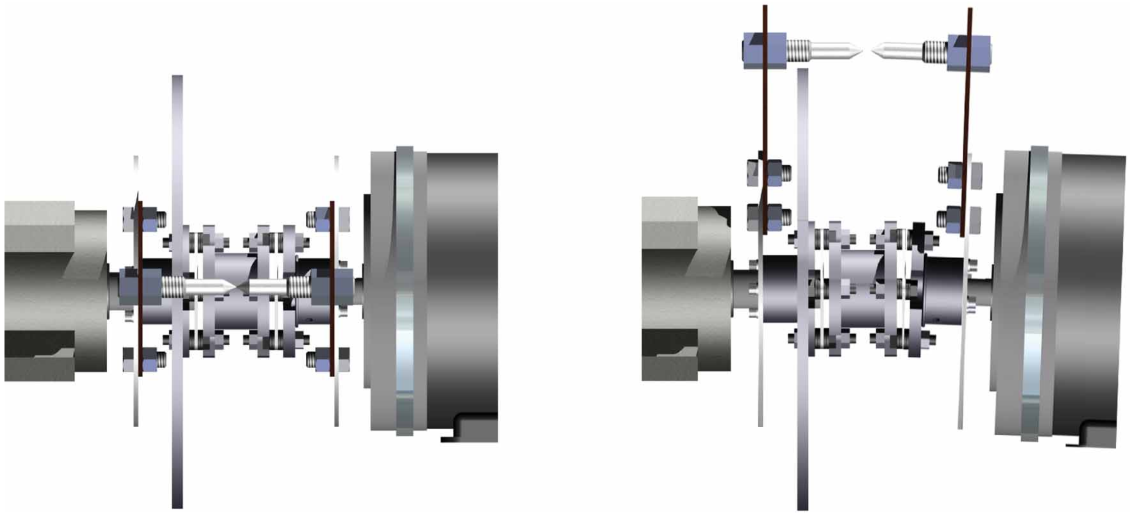


**Figure 2-63. Horizontal offset (view from the top).**

**52.** Reposition the stylus points when the shaft is at the 0° position. Rotate the shafts and verify that the horizontal distance remains minimal. Repeat the previous step if necessary.

**53.** Rotate the shaft between the 0°, 90°, and 180° positions once more and verify that no angular or parallel misalignment remains. Repeat appropriate procedure steps if necessary. Record any relevant observations such as major difficulties or remaining misalignment.

____________________________________________

____________________________________________

____________________________________________

**54.** Remove the alignment kit and reinstall the inductive sensor at the top of the slot. The distance between the sensor and the perforated disk should be about 3 mm (0.12 in).

*If you install the sensor at the bottom of its slot, the sensor will detect only half of the perforations it should normally detect. This will generate an error next time the nacelle operates in automatic mode.*

**55.** Return the manual overrides of valves SV4 and SV6 to their original position and verify that the brake is on.

**56.** Close the safety panels.

### Result of the alignment

**57.** Ask everyone to remove their individual padlock and tag. Next, remove the hasp from the main switch.

**58.** Restart the trainer and compare the vibration level to what you had before the alignment. Tell your instructor about any unusual situation. Note your observations below.

______________________________________________________________

______________________________________________________________

**59.** Have you succeeded in diminishing the vibration level?

❑ Yes ❑ No

### End of the procedure

**60.** Perform a final system shutdown.

**61.** Clean the area and, more specifically, the pan and the funnel that were used to change the gearbox oil.

## CONCLUSION

In this exercise, you became familiar with the high-speed part of the drive train system between the gearbox and the generator. More specifically, you checked gearbox temperature at rest and during operation, analyzed vibration on the gearbox, changed the gearbox oil, and aligned the shafts.

## REVIEW QUESTIONS

1. When should you change the oil of a gearbox?

______________________________________________________________

______________________________________________________________

2. What are the two elements supporting the gearbox on the nacelle training system?

______________________________________________________________

______________________________________________________________

______________________________________________________________

3. What is the speed of the high-speed shaft of the training system if the low-speed shaft is running at 40 RPM?

4. Why is there a thermocouple attached to the gearbox?

5. Which type of misalignment is corrected by placing shims under the front feet of the generator?

# Unit Test

1. Which of the following components is not part of the drive train system?

    a. Gearbox
    b. Low-speed shaft
    c. Yaw brake
    d. Hub

2. In a wind turbine, the electrical output power is a function of the

    a. efficiencies of the drive train system components.
    b. wind speed.
    c. rotor angular speed.
    d. All of the answers above are correct.

3. Which aerodynamic force type supplies most of the power extracted by wind turbines?

    a. Thrust
    b. Weight
    c. Lift
    d. Drag

4. If we consider 0° to be the hub rotational plane angle, what is the blade pitch angle in the feathered position?

    a. 0°
    b. 45°
    c. 90°
    d. None of the answers above is correct.

5. What type of lubricant is used for the bearings supporting the low-speed shaft?

    a. Water
    b. Grease
    c. Oil
    d. None of the answers above is correct.

6. What can be happening inside the gearbox if the speed ratio between input and output shafts is not constant?

    a. Slippage occurs at the shrink disk connection.
    b. Oil temperature is too high.
    c. Oil temperature is too low.
    d. None of the answers above is correct.

7. What are the two main types of shaft misalignment?

   a. Offset and radial
   b. Parallel and radial
   c. Offset and parallel
   d. Offset and angular

8. When do you have to check shaft alignment?

   a. When the machine is put in service.
   b. When the gearbox is replaced.
   c. When the generator is replaced.
   d. All of the answers above are correct.

9. What can a high vibration level not indicate?

   a. Component wear
   b. Wind station feedback problem
   c. Bolt loosening
   d. Alignment problem

10. Which ingredient differentiates greases from oils?

    a. Thickening agent
    b. Base oil
    c. Rust inhibitor
    d. Antifoam agent

Samples

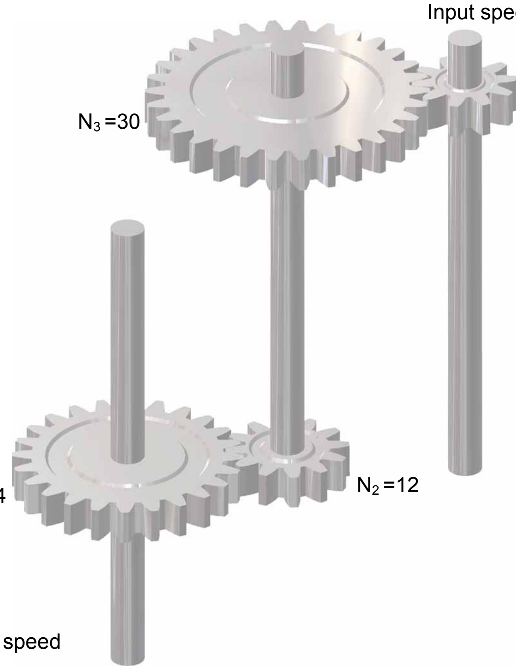
Extracted from

Instructor Guide

# Exercise 2-1 Hub and Low-Speed Shaft

**ANSWERS TO PROCEDURE STEP QUESTIONS**

**1.** The first gear must have twice the number of teeth of the second gear.




**Two stages of reduction.**

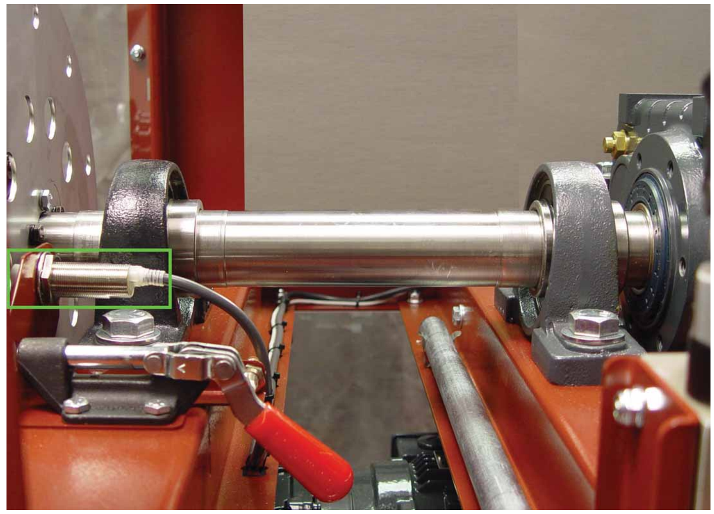
**2.** (12/24)*(10/30) = **1/6**

**14.**

| Step | Wind Speed (m/s [mph]) | Blade angle command (°) | Blade angle actual position (°) | Gearbox input speed (RPM) |
|---|---|---|---|---|
| 1 | 10 (22.4) | 5.1 | 5.9 | 48 |
| 2 | 12 (26.8) | 5.8 | 6.3 | 48 |
| 3 | 18 (40.3) | 22.8 | 22.5 | 48 |

**15.** Blade angle increases with speed as the blades are taken out of the wind when the wind speed exceeds the nominal value of 12 m/s (26.8 mph).

**16.** The sensor is located next to the rotor lock.



**17.** Inductive sensor.

**18.** The speed of the low-speed shaft remains relatively constant during energy production. This is explained by the fact that the gearbox ratio is fixed and that the generator must rotate at a specific speed, depending on the network frequency (e.g., 1800 RPM at 60 Hz and 1500 RPM at 50 Hz).

**20.** No. The vibration level reaches a peak after wind steps transitions, as the shaft speed and yaw position vary.

**25.** There shouldn't be anything unusual. If in doubt, contact Lab-Volt services.

**35.** There shouldn't be anything unusual. If in doubt, contact Lab-Volt services.

**37.** There shouldn't be anything unusual. If in doubt, contact Lab-Volt services.

**39.** The bolts can safely be adjusted to 35.2 N·m (26 lbs·ft or 312 lbs·in), which is beyond the range of the provided torque wrench. Therefore, students are less likely to over-torque the bolts. However, 28.2 N·m (250 lbs·in) is sufficient for this application.

If you wish, you can loosen a bolt or two using a ratchet so the students get a better feeling of the procedure.

**43.** The student should be able to see 2 to 4 gears, especially if flashlights are available.

**44.** The biggest gear is the first one on the left, aligned with the low-speed shaft. The reason why you have the biggest gear with the most teeth at the input of the gearbox is because the output shaft needs to be accelerated.

**45.** Helical

**46.** Shell Gadus S2 V220 2 or equivalent.

**50.**

*In factory, the pillow block bearings receive two pump strokes per quarter turn. You can ask the student to pump only once to limit excess grease in the assembly. Excess grease will escape through the shields during normal nacelle operation.*

*A better option is to pump grease into the additional (smaller) pillow block assembly instead to avoid the possible mess and additional friction load on the shaft.*

## Answers to Review Questions

1. Grease gun and grease (cartridge)

2. The hub (by pitching the blades)

3. Torque wrench

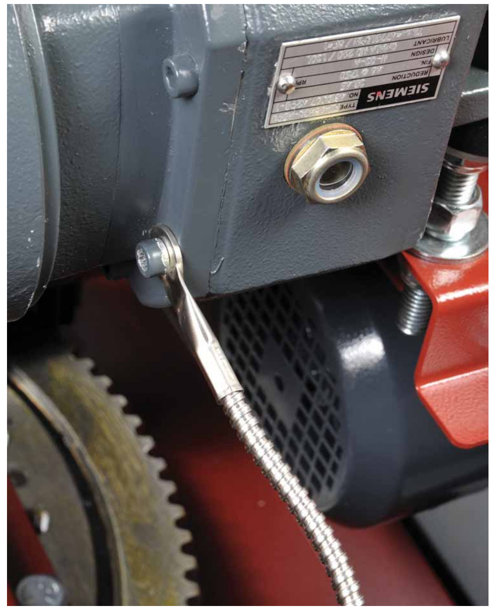
4. Score marks can indicate slippage.

5. Helical gears

# Exercise 2-2 Gearbox, Coupling, and Alignment

**ANSWERS TO PROCEDURE STEP QUESTIONS**

1. The thermocouple is attached to a bolt at the bottom of the casing, on the high-speed shaft side.




**Location of the gearbox thermocouple.**

2. **<u>Suggestions to the instructor</u>**

At this point, you can:

- remove some oil from the gearbox or spill some oil near the gearbox and observe if the students notice at steps 4 and 6 of the student manual.
- misalign the shafts by modifying the torque arm height or by removing or adding some shims under the generator.

*The coupling can be damaged if there is too much misalignment. Refer to the table of allowable shaft misalignment in Appendix G if necessary.*

4. Answer should be yes. If the level is very different, consider adding/removing oil now to avoid damage to the gearbox.

5. Answer should be no. If yes, consider changing the oil now to avoid damage to the gearbox.

6. Answer should be no.

**7.** Two types of oil are present on the system: hydraulic and gearbox oil. Under normal circumstances (if you did not spill some on purpose), there should be no oil leak. In the long run though, the housing and shaft seals of the gearbox may lose some of their tightness.

**15.** The value depends on the classroom temperature and if the trainer was used recently. As a reference, we obtained a value of 22.0°C (71.6°F) in our facilities.

**20.** Normal maximum vibration level should be around the warning level of 15 mm/s (0.6 in/s).

**21.** No, vibration is not constant. The vibration level is temporarily higher at given shaft speeds during acceleration (i.e., at speeds multiple of the resonant speed). Wind step transitions can also trigger some instability, as the shaft speed and yaw position vary. In general, higher wind speeds generate more vibration (e.g., at 12 m/s vs. at 10 m/s).

**22.** We obtained a value of 26.0°C (78.8°F) after ten minutes of operation in our facilities.

**23.** The new value is higher. This means that the temperature increases during nacelle operation. This is mainly due to gear tooth friction and oil splash losses.

**41.**

*The following procedure may take a while. You may want to limit the intervention of the student to just installing the alignment kit and observing any residual misalignment.*

**46.**

*The students will likely manipulate the nuts holding the styluses repeatedly. It can be sufficient and certainly more convenient to secure them using only one's hands.*

**53.** Note to the instructor: it may be a good idea to verify the alignment yourself before the alignment kit is put away.

**CAUTION**

Make sure the generator bolts and the gearbox torque arm nuts are all tightened sufficiently.

**58.** The important point here is to make sure the system will be in good working condition for the following team.

**59.** Answer should be yes.

## ANSWERS TO REVIEW QUESTIONS

1. You should change the oil after a certain number of hours of operation, or if it changes color or appearance.

2. The gearbox is supported by the low-speed shaft and the torque arm bolt.

3. The high-speed shaft should run at around

$$40 \text{ RPM} \times 38.45 = 1538 \text{ RPM}$$

4. The thermocouple provides feedback about the gearbox temperature to maintain the system in reasonable conditions of operation.

5. Angular misalignment

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