

V O L V O P E N T A

ANODES Q&A

Confidential – Internal use only



Genuine Volvo Penta sacrificial anodes

Questions and answers about Genuine Volvo Penta sacrificial anodes and our updated guidelines on which type of anode alloy to choose for best corrosion protection of drives and folding propellers.

The conclusions in this Q & A refer to using Genuine Volvo Penta anodes.



Table of content

| | |
|--------------------------------------|--------------|
| Introduction – Question 1–8 | Page 3 – 5 |
| In depth information – Question 9–24 | Page 6 – 10 |
| Supplementary information | Page 12 – 16 |

Introduction

1. Different water environments require different anode alloys.

What does Volvo Penta recommend to secure proper corrosion protection?

- In salt and brackish water, we recommend aluminum anodes, however zinc anodes are also suitable.

| | Salt Water* | Brackish Water* | Fresh Water |
|-----------|-------------|-----------------|-------------|
| Aluminum | ✓ | ✓ | — |
| Magnesium | — | — | ✓ |

* Select zinc anode if aluminum anode is not provided for your product.

2. Why do you recommend aluminum over zinc anodes in salt water?

- Aluminum anodes offer many benefits over zinc anodes. To begin with, they have a higher driving voltage and thus higher corrosion protection capacity and last longer than zinc anodes. They are also less toxic, which gives less environmental impact. In addition, aluminum anodes are a better choice also for brackish water.
- Aluminum anodes provide up to 30% higher corrosion protection capacity and last up to 20-40% longer than zinc anodes of comparable size in salt water.

3. Zinc anodes have been recommended as best choice for salt water for decades? What has happened?

- Zinc has been around for much longer and almost been an institution in the traditional world of boats and yachts; it has even become the common word for sacrificial anodes, and you can use such a contradictive expression as “aluminum zincs”.
- The early aluminum anode alloys were alloyed in a way that made them less effective than zinc anodes and passivated more easily in many waters and some of them also contained mercury, which is harmful for the environment.
- However, alloying has developed over the years and the aluminum anodes Volvo Penta offered today are more effective than zinc anodes. In the off-shore, pipeline and ship industries, aluminum anodes have almost completely replaced zinc for saltwater applications.

4. Will Volvo Penta continue to provide zinc anodes when aluminum anodes are a better choice for both salt and brackish water?

- We will gradually phase out and replace most of our zinc anodes with aluminum anodes for Aquamatic Sterndrives, S-drives and propellers as of Sep 1st 2021. However, we will continue to provide zinc anodes for a few of our oldest drives. See chart in the section “Supplementary Information” at the end of the Q&A.
- Volvo Penta drive maintenance kits will be updated with aluminum anodes instead of zinc as of Sep 1st 2021
- We will continue to provide back-up anodes made of zinc for Active Corrosion Protection (ACP).

5. Will the drives in production have factory fitted aluminum anodes?

- All Aquamatic Sterndrives (SX, DPS, FWD, DPH, DPI) are now delivered with factory-fitted aluminum anodes.
- S-drives (130S, 150S) and folding propellers will have factory-fitted aluminum anodes during 2021, target date is Sep 1st 2021.

6. Are aluminum anodes more expensive than zinc anodes?

- The price of our aluminum anodes will match the price for equivalent zinc anode. However, the longer life of aluminum anodes, which most customers will experience, results in lower maintenance cost over time.

7. Are all aluminum anodes equally good?

- There are many manufacturers of aluminum anodes but not all are of the same quality. The grade and the composition are key to the performance of the anode. Even the slightest amount of impurities will significantly reduce the corrosion protection performance of aluminum anodes (see graph in the section “Supplementary Information” at the end of the Q&A).
- The performance benefits of aluminum anodes stated in this Q&A are based on the use of Genuine Volvo Penta aluminum anodes.
- To work properly, it is also important that anodes have good electrical contact with the metals they are protecting. Volvo Penta anodes have (when needed) an internal reinforcement of an alloy that is not consumed. This ensures a reliable attachment and a good electrical contact even when the anode naturally deteriorates.
- Volvo Penta has, over the last few years, worked and invested intensively in the quality of the aluminum alloy, manufacturing processes and quality control system to secure a high degree of purity of the alloy which is needed for it to function well.



8. There are many competitors providing aluminum anodes to VP installations, why should customers buy Volvo Penta genuine anodes?

- Inserts to secure electrical connection to installation
- Pure aluminum alloy
- Stringent quality controls
- Designed, tested and approved for Volvo Penta installations to fulfill Volvo Penta high quality requirements

In depth information

9. Why do aluminum anodes protect better than zinc anodes?

Is it true both in salt and brackish waters?

- As aluminum anodes are approximately 50 mV more electronegative than zinc anodes, the driving voltage to protect the drive is greater using aluminum anodes.
- Aluminum anodes provide approximately 30% higher corrosion protection capacity than zinc anodes. This is as true in salt as well as in brackish waters down to very low salinities (about 0,4%), i.e. close to freshwater, where the benefit gradually diminish.

10. Why do aluminum anodes last longer than zinc anodes?

- They have a much higher current capacity than zinc anodes (2530 A·h/kg compared to 738 A·h/kg) and although the density of aluminum is almost 1/3 of zinc, the current capacity per volume unit is still higher. Therefore, an aluminum anode of the same size will last longer.
- The difference in longevity can be demonstrated by a consumption rate calculation using theoretical current capacity values provided by the EN 12496 standard for sacrificial anodes. This standard mentions 3.50 kg/A·y as aluminum anode current capacity and 11,2 kg/A·y for zinc anodes. Dividing those numbers with the density for each material, we find that the consumption rate can also be expressed as 1,30 dm³/A·y for aluminum and 1,60 dm³/A·y for zinc, i.e. the aluminum anode is consumed at a slower rate with, according to those numbers, approximately 25% longer life.
- However, the actual advantage in anode life varies significantly depending on the particular operating conditions of the anode. This is also the reason why different sources and manufacturers quote different ranges. Learn more in next question.

| | Zn | Al |
|------------------|--------------------------|--------------------------|
| Capacity | 738 Ah/kg | 2530Ah/kg |
| Consumption | 11,2kg/A·y | 3,5 kg/A·y |
| Consumption rate | 1,60dm ³ /A·y | 1,30dm ³ /A·y |
| Potential | -1030 mV _{SCE} | -1100 mV _{SCE} |

11. Will aluminum anodes last longer than zinc anodes in all operating conditions?

- For installations that require a low protection current and thus have a low consumption rate, the longevity will be comparable between zinc and aluminum anodes, whereas those with a higher current demand will experience increased life using aluminum anodes with up to 20 – 40%.
- The advantage in longevity varies depending on the water environment where the boat is used and the product the anode is protecting, which in turn is affecting the anode current density:

| Anode Operating Conditions | Anode Current Density / Advantage using aluminum vs zinc | |
|-------------------------------------|--|--------------|
| | Low | High |
| Water conditions | Stagnant water | Moving water |
| How much the boat is used | Seldom | Frequently |
| Water temperature | Warm water | Cold water |
| Bare metal surface areas to protect | Small areas | Large areas |

- At high anode current density, the advantage in service life of using aluminum anodes is most significant.
- In brackish waters with very low salinities, the benefit gradually diminish. The most conservative value mentioned in a standard used for cathodic protection design purposes, indicates equal life for aluminum and zinc anodes. However, this is deliberately low, in order not to overestimate aluminum capacity even at extremely low anode current densities.

12. Why are aluminum anodes a better choice for the environment than zinc anodes?

- Aluminum anodes are generally less toxic for marine organisms, which is particularly important in marinas where concentrations increase and the reason why legislations regarding zinc anodes are discussed in many places. Authorities and organizations in US (EPA / Marine Trade Association of Baltimore County / Connecticut Department of Environmental Protection) are recommending the use of aluminum instead of zinc based on environmental considerations.
- Small amounts of zinc are essential for the human body, but in higher concentrations it is toxic to the environment. Zinc anodes usually contain a certain amount of an activator to prevent passivation in certain conditions, for this purpose many manufacturers of zinc anodes use small amounts of very toxic cadmium.
- Aluminum anodes are cadmium free, instead indium is used as activator. The longer life of aluminum anodes will also reduce the number of anodes consumed over time.
- The lower weight of aluminum will lower the impact from transportation.

13. Has Volvo Penta done any testing that proves the benefits of aluminum compared to zinc anodes?

- Volvo Penta has performed extensive field tests in various locations around the world. They were carried out in different water environments with varying salinity and current density levels. In addition, we have also conducted comprehensive laboratory testing for a long time.
- The results of the tests are consistent and verify the benefits of using Volvo Penta aluminum anodes compared to zinc anodes in both salt and brackish water.
- The field tests were performed during 2018 in: Venice (Italy), Florida and Virginia (USA), Oslo and Alesund (Norway), Krossholmen (Sweden).

14. Can you mix aluminum and zinc anodes on the same drive?

- Aluminum and zinc anodes are compatible from a technical standpoint and may be mixed on the same drive.
- It will result in a more uneven anode consumption rate, where the zinc anode being consumed more slowly and the aluminum anode faster than normal. Although the total consumption is unchanged.
- Mixing zinc and aluminum anodes on the same drive will lead to higher protection capacity compared to if you use only zinc anodes. If you use only aluminum anodes the protection capacity increases even further.
- **NOTE!** Boats with aluminum hull or extra equipment protected by additional zinc anodes, we strongly recommend that those anodes are changed to aluminum anodes to avoid extremely high consumption rate of the aluminum anode on the drive.
- For more information, see “Supplementary Information”, at the end of the Q&A.

15. Can aluminum anodes be used for all types of hull materials?

- Yes, no difference compared to using zinc anodes.

16. How can aluminum anodes protect drives made of aluminum?

- The drive and anode alloys are completely different. The anode is alloyed solely to prevent passivation and to make it less noble and thus reduce the galvanic potential compared to the drive. In fact, aluminum anodes are even less noble than the zinc anodes and thus offers a higher driving voltage towards the drive.

17. What happens if the boat moves between salt and fresh water when using aluminum anodes?

- If left in fresh water for some time, both aluminum and zinc anodes run an increased risk of being passivated. Learn more in the next question.

18. Is there any difference between aluminum and zinc anodes when it comes to the risk of passivation?

- Passivation means that the anode becomes covered by an insoluble surface film that prevents it from working properly. This occurs for both zinc and aluminum anodes under certain conditions.
- Zinc anodes run a higher risk in waters dominated by carbonates, bicarbonates and nitrides and the risk increases with reduced salinity for both types of alloys. Aluminum is more sensitive to very low chloride levels than zinc anodes, i.e. brackish close to freshwater.
- When aluminum or zinc anodes have been in fresh water or exposed for air for some time, it is considered good practice to rub them with emery paper to ensure they are active and work properly.
- **NOTE!** Do not use sandpaper, wire brush or other steel tools when cleaning, as these may damage the galvanic protection.

19. Why are magnesium anodes the choice for fresh water environments?

- Magnesium anodes have a much higher driving voltage than aluminum and zinc anodes, which is needed to provide sufficient corrosion protection in fresh water, as the electrical conductivity is much lower than in salt and brackish water.
- Magnesium anode potential is approx. $-1500 \text{ mV}_{\text{SCE}}$, which gives a driving voltage of 550 mV (after anode polarization) to the protection potential requirement for aluminum parts, which is $-900 - -1100 \text{ mV}_{\text{SCE}}$. The corresponding driving voltage for aluminum anodes is 150 mV in brackish and salt water, but even lower in freshwater due to passivation and potential shift. Also, the current capacity of aluminum anodes drops significantly in such low salinity waters.
- It becomes particularly important for units made of dissimilar metals far apart in the galvanic series (big potential difference) such as aluminum and stainless steel, where galvanic corrosion is likely in case of insufficient cathodic protection. This includes products such as Aquamatic Sterndrives and S-drives.
- Aluminum and zinc anodes run also an increased risk of shifting to more noble potentials by passivating surface films in fresh water, particularly at low anode current densities, which stops them from working properly.
- **NOTE!** Magnesium anodes should not be used in salt or brackish water due to risk of overprotection and extremely high anode consumption.

20. You do not offer magnesium anodes for Volvo Penta IPS.

What is the reason?

- For Volvo Penta IPS, aluminum transom anodes can be used also in freshwater.
- The IPS drive are made entirely of noble alloys and have large bare metal surfaces. Therefore, the anode current density is usually high and the required protection potential is quite electropositive (-450 mV compared to -900 mV for Aquamatic/S-drives). Consequently, the risk for passivation is lower and there is still a significant driving voltage also with a passivated anode.

21. Why do Volvo Penta continue with zinc back up anodes for Active Corrosion Protection (ACP)?

- The back up anode for the ACP system is not intended to work actively, but to be ready when the ACP switch over to passive mode.
- Marine fouling is not a problem for sacrificial anodes that provide cathodic protection (CP) for two reasons: the surface is continuously renewed and simple marine organisms are repelled by the ion release/electric current. Those marine organisms are a pre-requisite for more advanced fouling such as algae and barnacles.
- When inactive, there is no CP current. However, the anode will still experience self corrosion with a very slight ion release. Simple marine life tend to avoid zinc as it is experienced as slightly toxic to such organisms, similarly as but to a lesser extent than copper that is a common antifoulant. This is not the case with aluminum.
- Therefore, aluminum anodes that are not active in providing cathodic protection eventually tend to be overgrown and the ability to provide CP once needed becomes significantly impaired.

22. Is it more difficult to provide correct cathodic protection in salt water?

- Contrary to what many people think, salt waters are the easiest when it comes to providing adequate cathodic protection. Yes, it is more corrosive than brackish water, but since the resistivity is lower it is also much easier to get the electric current required for proper protection.
- In salt water, both aluminum and zinc anodes will work well. The current demand does not change with salinity, only resistivity. Decreasing the salinity, there is a point for each cathodic protection system where the protection potential can no longer be maintained. With the higher driving voltage offered by aluminum anodes compared to zinc anodes, this critical salinity level is pushed further down.

23. If I change from zinc to aluminum anodes, do I need to change anything on the drive, propeller etc., i.e. attachment principle/components and are there any other inserts, attachment etc. of the hull that could be affected by the anode alloy change?

- No

24. When should anodes be replaced?

- Anodes should be inspected at regular intervals and be replaced when they have eroded to half their original size.
- When installing a new anode, make sure it is good electrical contact between the anode and the surface to which it is connected.
- A new anode has often been exposed to air for a long time, which means that the anode can be covered by a passivating surface film that prevents it from working properly. A good piece of advice is to reactivate the anode before launching the boat, e.g. by grinding with emery paper. **NOTE!** Do not use sandpaper, wire brush or other steel tools when cleaning, as these may damage the galvanic protection.



VOLVO

VOLVO

VOLVO

VOLVO

VOLVO

Supplementary information

Supplement to question 4 on page 4.

What does all this mean for the future. Will Volvo Penta stop providing zinc anodes?

- Not entirely, for some older drives zinc will still be the only alternative available. (marked with Zn in table below) See chart of Volvo Penta anodes for drives and folding propellers below.

Aquamatic Sterndrive - Single Prop Drives

| Lower Gear | Salt and Brackish Water (Al*) | Fresh Water (Mg) |
|-----------------------|-------------------------------|------------------|
| 100 Drive | 875810 (Zn) | — |
| 200-290, SP | 875815 (Zn) | 876137 |
| Spray Plate | | |
| SX | 3863193 | 3855412 |
| SX-A | 23164609 | 3888815 |
| Transom Shield | | |
| 200–280 | 832598 (Zn) | 873179 |
| 290, SP | 3588770 | 3588768 |
| SX | 3586461 | 3855610 |
| SX-A | 23164611 | 3888818 |

Aquamatic Sterndrive - Duo Prop Drives

| Lower Gear | Salt and Brackish Water (Al*) | Fresh Water (Mg) |
|---------------------------|-------------------------------|------------------|
| 280, 290, DP | 23974010 | 876138 |
| Spray Plate | | |
| DP-S, DP-SM | 3863193 | 3855412 |
| DPS-A, DPS-B, FWD | 23164609 | 3888815 |
| DPR, DPH, DPI | 23520859 | 23520860 |
| DPX | 876638 (Zn) | |
| Transom Shield | | |
| 280 | 832598 (Zn) | 873179 |
| 290, DP | 3588770 | 3588768 |
| DP-S, DP-SM | 3586461 | 3855610 |
| DPS-A, DPS-B, FWD | 23164611 | 3888818 |
| DPH, DPR, DPI | 3588770 | 3588768 |
| DPX | 23813192 | 24042665 |
| Exhaust Pipe | | |
| DPH, DPI, DPR | 21868042 | 21868041 |
| Fork | | |
| | 23986753 | 23986752 |
| Intermediate house | | |
| DPX | 24007660 | 3863480 |

* For some older drives, cadmium-free zinc anodes (marked with Zn) are provided for salt and brackish water environments instead of aluminum anodes.

The chart continues on next page.

S-Drives

| Lower Gear | Salt and Brackish Water (Al*) | Fresh Water (Mg) |
|----------------------------|-------------------------------|------------------|
| 110S | 875812 (Zn) | 876603 |
| 120S, MS25S | 23973978 | 876604 |
| 130S, 150S (2 piece anode) | 23615636 | 22651247 |

Folding Propellers

| S-Drive | Salt and Brackish Water (Al*) | Fresh Water (Mg) |
|--|-------------------------------|------------------|
| 2-blade & 3-blade | 23974203 | 3858400 |
| 4 -blade propeller | 23974205 | 3584443 |
| Shaft | | |
| 2-blade propeller | 23974207 | 3888493 |
| 3-blade propeller (use anode for shaft mounting) | - | - |
| 4-blade propeller | 23974203 | 3858400 |

Volvo Penta IPS

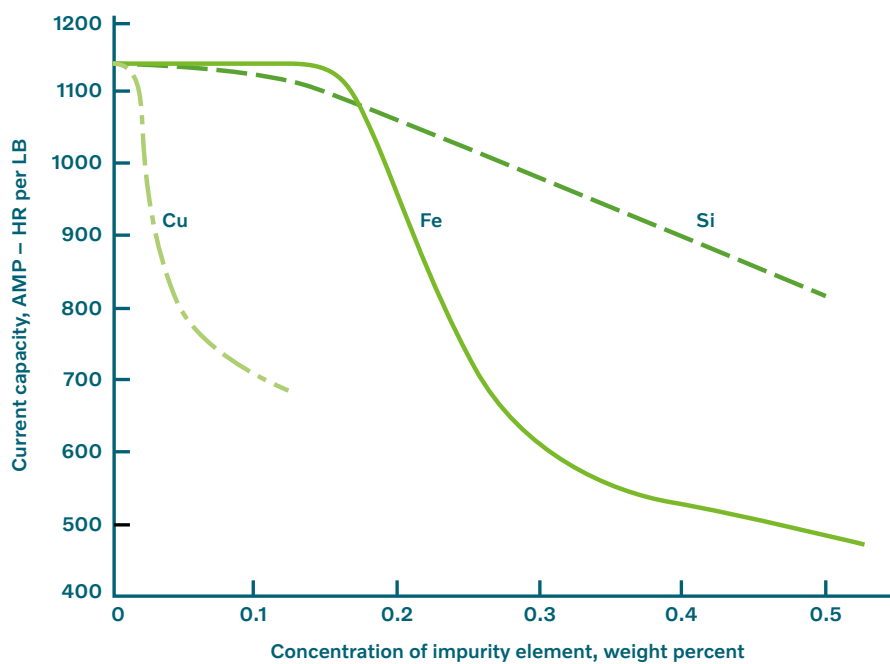
| Salt, Brackish and Fresh Water | |
|---------------------------------------|----------|
| Lower Gear | 3593981 |
| Transom anode IPS1/10 | 23172849 |
| Transom anode IPS15, IPS2/20, IPS3/30 | 23172856 |

* For some older drives, cadmium-free zinc anodes (marked with Zn) are provided for salt and brackish water environments instead of aluminum anodes.

Supplement to question 7 on page 4.

Are all aluminum anodes equally good?

- The graph shows that even the slightest amount of impurities will significantly reduce the current capacity and thus the corrosion protection performance of aluminum anodes.

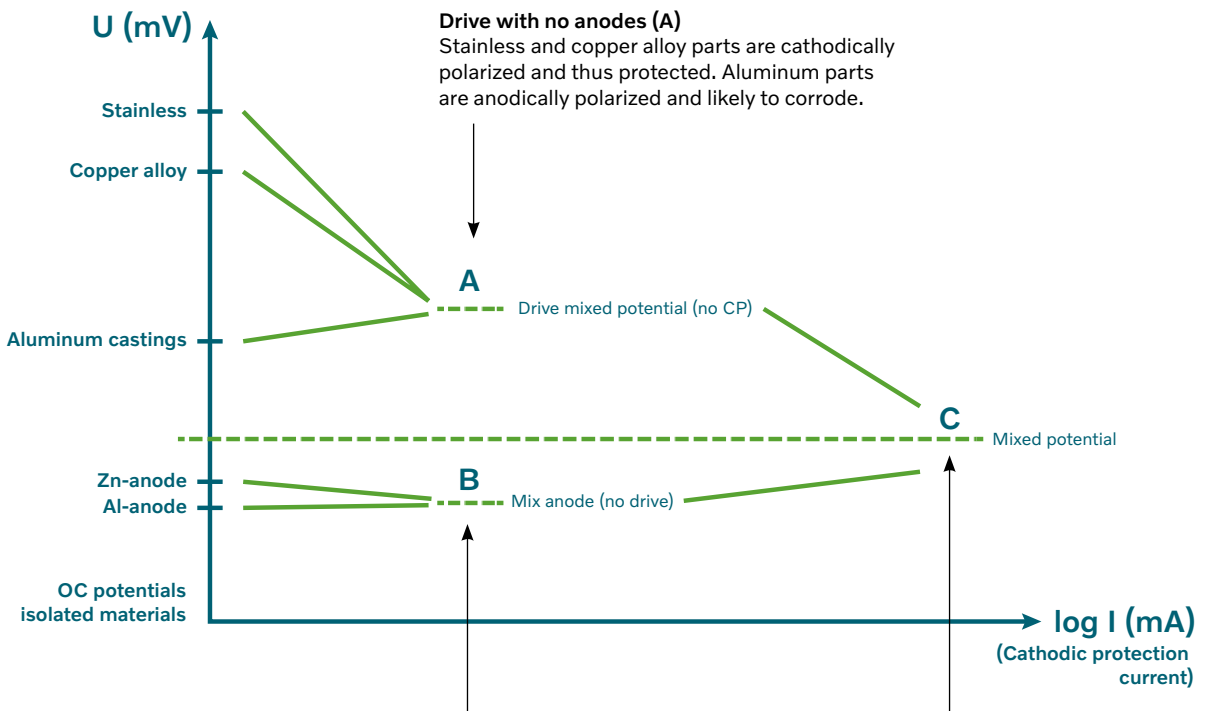


Gibson G., Behavior of Al-Zn-In Anodes at Elevated Temperature, Paper No. 10396, NACE Corrosion 2010.

Supplement to question 14 on page 8.

Can you mix aluminum and zinc anodes on the same drive?

- Some sources claim you should never mix anodes, saying that the least noble (aluminum) will also act to protect the zinc anode, thus having an increased area to protect.
- In fact, mixing anode metals does not mean they are consumed successively one after the other starting with the least noble alloy as one might spontaneously believe. Instead, the truth is that in a system with different alloys electrically coupled and immersed in an electrolyte, they will all balance at a mixed potential.
- All alloys negatively polarized from their open circuit (OC) potentials, i.e. mixed potential lower than their potential when isolated from any other metal, will corrode less or not at all. Alloys positively polarized from their OC will corrode. **This is illustrated in the graph below considering three scenarios.**

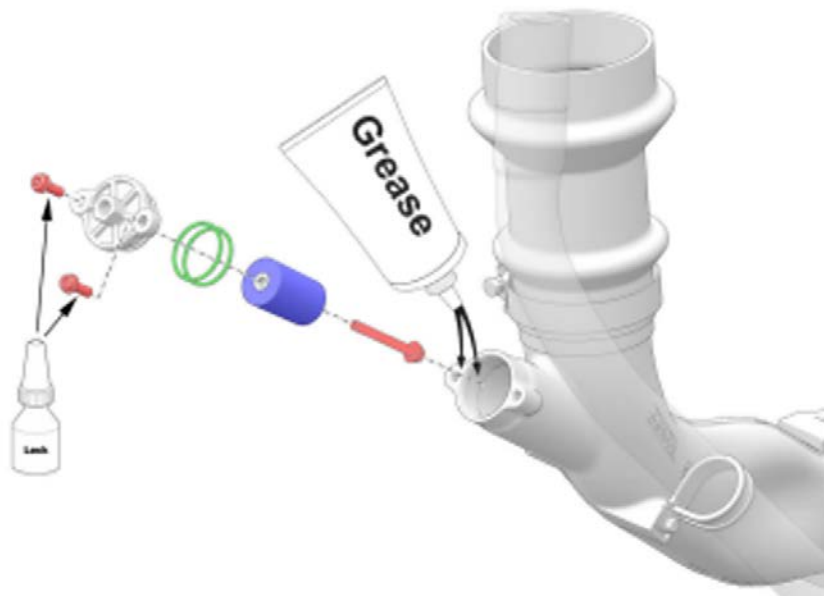


Aluminum and zinc anodes fitted with no other material attached (B)
The aluminum anode will be anodically polarized and corrode while protecting the zinc anode.

Complete drive with mixed anodes (C)
The mixed potential will be at a more electro-positive value than the OC of both the zinc and aluminum anodes though clearly lower than that of any constituent drive alloys. This means that both anodes will be anodically polarized and assist to provide cathodic protection to the drive.

Continues on next page...

- In an extreme case scenario where the mixed potential is less noble than the open circuit (OC) potential of the zinc anode, a portion of the protection current from the aluminum anode will protect the zinc and there is a slightly increased risk that the zinc anode is passivated. However, a pre-requisite for this scenario to occur is that the CP current required by the protected component is extremely small, in which case the anode consumption rate is very low and the fact that the potential is between the OC potentials of the anodes inevitably means that the protection criterion is fulfilled.
- With aluminum anodes on the drive, many boat owners will note that the exhaust pipe anode is consumed more slowly or almost not at all. The reason is that the CP current from the aluminum drive anodes reach into the exhaust system and thus assist the zinc anode in protecting the interior surfaces. Some believe that the reason is that aluminum anodes block zinc anodes from functioning, which is not the case. Consequently, this means that the cathodic protection is improved rather than reduced.



Disclaimer

Every effort has been made to ensure that facts and figures are correct at the time of publication. Volvo Penta reserves the right to make changes to the statements and descriptions in the Q&A without prior notice at any time.

The conclusions in this Q & A refer to using Genuine Volvo Penta anodes.

V O L V O P E N T A