The Future Pioneered by the Nanopump®

October 21, 2024, Upfield, LLC

1. Addressing Climate Change

As the threats of climate change intensify, it often seems that global warming has reached an irreversible point. Nevertheless, there are still actions we can take to safeguard the future. To make the planet more sustainable and to pass it on to the next generation, we urgently need innovative technologies that significantly reduce environmental impact. One such solution is the Nanopump® technology.

The Nanopump® can deliver an astonishingly small amount of lubricant with precision, dramatically reducing lubricant consumption. Its widespread adoption could represent a crucial step toward combating global warming. Here are the reasons why:

1). Significant Reduction of Lubricant Consumption

If the use of lubricants can be reduced to less than one-hundredth of current levels, the environmental impact across all processes—manufacturing, transportation, and disposal—will be dramatically diminished. This reduction is particularly crucial in the manufacturing of petroleum-based lubricants, which consumes a substantial amount of energy, directly lowering greenhouse gas emissions.

2). Improved Energy Efficiency

Nano lubrication technology significantly reduces friction and wear, enhancing the energy efficiency of machinery. This leads to a decrease in the energy required for operation, subsequently reducing carbon dioxide emissions. Its application in industrial machinery and vehicles can result in a notable reduction in global energy consumption, with far-reaching implications.

3). Reduced Maintenance and Waste

More effective lubrication extends the lifespan of machinery and decreases the frequency of maintenance. This reduction translates to less resource and energy consumption for repairs and parts replacement, while also minimizing waste generation. Particularly, the handling and disposal of used lubricants can have detrimental effects on the environment, making their reduction a critical issue.

4). Improved Factory Environment

Excessive lubricant use within factories can lead to oil mist and water pollution. The significant decrease in lubricant consumption enabled by Nano lubrication technology can mitigate air and water contamination in factories, thereby enhancing the working environment and reducing health risks for employees. Additionally, the reduced need for oil recovery equipment and mist collectors can contribute to further energy savings.

5). Sustainable Resource Utilization

Protecting our finite oil resources is our responsibility to future generations. The reduction in lubricant consumption through Nanopump® technology is part of sustainable resource utilization, helping to mitigate the long-term risks of resource depletion on a global scale.

The widespread adoption of Nano lubrication technology is expected to yield broad benefits in the fight against global warming, extending beyond mere reductions in lubricant consumption. It promises improvements in energy efficiency and waste reduction, among other advantages. By promoting this technology, we can envision a future where the carbon footprint of entire industries is significantly reduced.

Next, we will provide specific examples of how Nano lubrication technology can be applied to rolling bearings.

2. Challenging Low Torque Through Reduction of Lubricant Quantity in Rolling Bearings

1). Through many years of involvement in the development of rolling bearings, I have realized that even a slight reduction in rotational loss can bring significant benefits to the entire industry. This insight has driven us to tackle the challenging issue of achieving low torque.

2). A detailed analysis of bearing rotational torque revealed that to minimize rotational losses, it is essential to reduce both rolling friction and sliding friction within the bearing. However, achieving this requires not just technical improvements, but also the exploration of new approaches that maintain high quality.

3). As a result, we discovered that the current lubricant supply is excessive. By finding the right balance, we can significantly reduce oil quantity while minimizing friction and avoiding risks of lubrication failure or seizing.

4). This challenge has led to further innovation, particularly in the bearings of machine tool spindles, where we are proactively addressing oil quantity reduction. We are committed to pushing boundaries in our efforts to enhance product performance through significant reductions in lubricant use.

3. Technological Innovations of the Nanopump®

1). Industrial pumps typically discharge in liters (l) or milliliters (ml). There are also smaller pumps that operate in microliters (μl) or picolitres (pl), particularly used in inkjet printers. However, pumps that can discharge nanoliters (nl) have been almost nonexistent. To fill this gap, we developed the Nanopump®.

2). When reducing the lubricant quantity in rolling bearings, two criteria must be considered: (1) supplying a minimum amount of oil that does not cause rotational disturbances or agitation resistance when lubricating, and (2) maintaining a sufficient lubrication level to prevent damage to the sliding friction surfaces within the bearing. It is challenging to achieve this balance at the picolitre level, making the nanoliter scale optimal, which our proprietary Nanopump® successfully addresses.

3). The Nanopump® is a groundbreaking technology capable of accurately and timely dispensing very small quantities of liquid, ranging from 10 nl to 90 nl. This technology prevents the frequent over-supply of lubricants seen in traditional lubrication systems, facilitating significant reductions in lubricant quantity. As a result, it enables efficient and environmentally friendly lubrication, greatly contributing to sustainable industrial processes.

4). Fig. 1 illustrates the appearance of the Nanopump®. This pump is remarkably compact, small enough to rest on a fingertip, yet capable of delivering precise amounts of liquid in the tens of nanoliter range. Thus, the Nanopump® functions as a "just-in-time" pump, supplying only the necessary amount at the right moment, making it a powerful technology that contributes to the Sustainable Development Goals (SDGs).

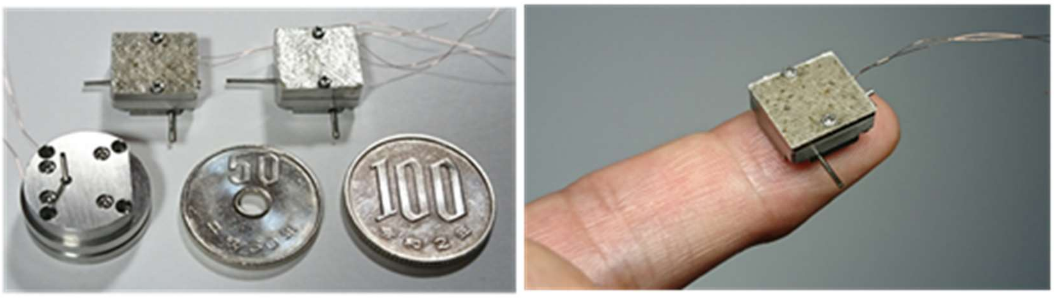


Fig. 1: Nanopump®

5). Table 1 outlines the main features of the Nanopump®. This pump can deliver extremely small quantities of oil independently, allowing for precise control over the supply volume by adjusting the discharge intervals. However, because the pump contains very narrow oil pathways, the presence of tiny contaminants or air bubbles in the oil can obstruct these pathways, potentially halting the discharge. Careful attention to this aspect is essential during use.

Table 1: Key Features of the Nanopump®

Features	1. Extremely compact size, allowing for easy installation at the supply point.
	2. Direct nozzle supply to the target location.
	3. Single discharge volume ranges from approximately 10 nl to 90 nl
	4. Independent discharge per operation.
	5. Required amount can be set by adjusting the discharge intervals.
	6. Operating cost is approximately 0.1 yen or less for continuous use over one year.
Weaknesses	1. Can only discharge have filtered, clean liquids.
	2. Discharge is not possible if air is trapped.

6). If the Nanopump® cannot be installed near the supply location, the use of the Nanopump® unit, as shown in Fig. 2, allows for the flexible supply of lubricant from a distance using flexible tubing. In practice, utilizing this unit offers greater design flexibility, making lubrication design for machinery easier, and it may become the mainstream solution in the future.

Fig. 2: Nanopump® Unit

4. The Evolution of Lubrication Methods for Rolling Bearings

1). Various oil lubrication methods used for rolling bearings are summarized in Table 2. Notably, "oil-air lubrication," which lubricates high-speed bearings with a minimal amount of lubricant, stands out among these methods. While this lubrication technique is commonly employed in machine tool spindles, it presents certain challenges, which we will address here.

Table 2: Types and Details of Oil Lubrication Methods

	Name	Description	Application	Oil Quantity
1	Oil Bath Lubrication	The simplest method involves immersing the bearing in oil during operation.	Low to Medium Speed	Many
2	Drip Lubrication	Drip lubrication using a lubricator.	High Speed, Medium Load	Medium
3	Spray Lubrication	Oil splash lubrication.	Medium Speed to High Speed	Many
4	Forced Circulation	Forced lubrication using a pump.	High Speed	Many
5	Jet Lubrication	Oil is injected from a nozzle at a constant pressure for lubrication.	High Speed, Heavy Load	Many
6	Oil Mist Lubrication	Lubrication with misted oil generated by an oil mist generator.	High Speed	Few
7	Oil-Air Lubrication	Oil droplets are transported along the inner walls of a narrow pipe for lubrication.	High Speed	Few

2). Fig. 3 illustrates the concept of the "air barrier" that forms on the side of a high-speed rotating bearing. For instance, when the inner ring of the bearing rotates at high speeds, it entrains surrounding air, creating a powerful "air barrier" along the side of the bearing. This is a well-known phenomenon, and this air barrier is a significant barrier that prevents lubricants from reaching the interior of the bearing.

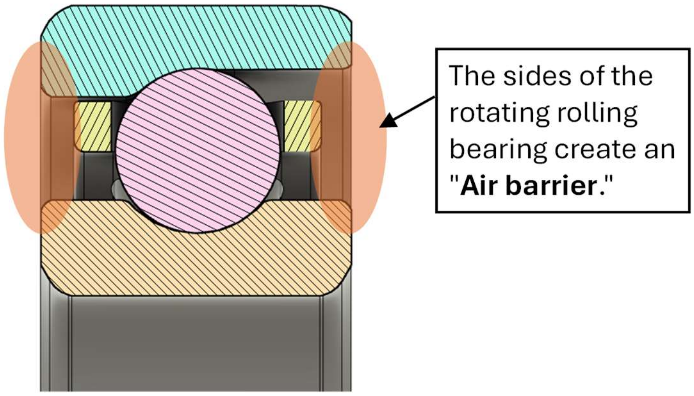


Fig. 3: "Air barrier" Formed on the Side of a High-Speed Rotating Bearing

3). Currently, there is no established optimal solution for addressing this "air barrier." Generally, methods such as increasing the pressure and flow rate of air to transport lubricating oil or increasing the volume of the lubricant itself to force it into the bearing, are commonly employed.

4). However, these measures have significant drawbacks. The efficiency of oil-air lubrication deteriorates, and the excessively supplied oil can be blown away by the air barrier, becoming mist and scattering. As a result, it is not uncommon for over 90% of the oil to be wasted without being utilized for lubrication.

5). To resolve this fundamental issue of the "air barrier," we propose Nanopump®. This innovative technology can precisely supply the minimum required amount of lubricating oil, enabling efficient and waste-free lubrication of the bearings.

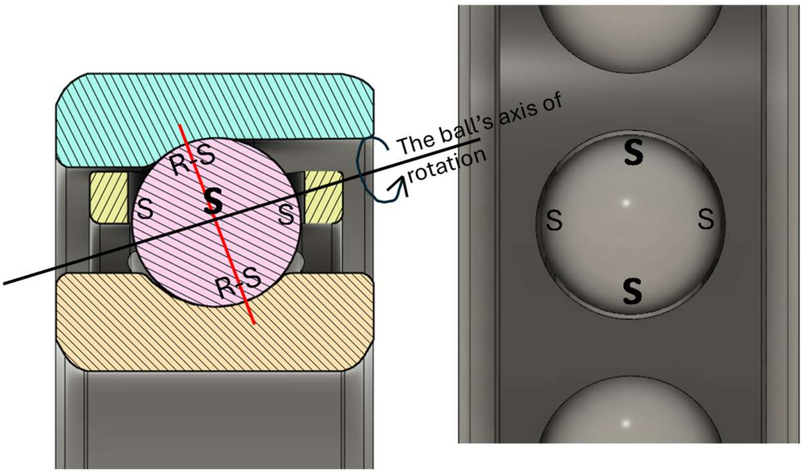
5. The Nature of Friction and the Application of the Nanopump®

1). Inside the angular contact ball bearings widely used in machine tool spindles, there are two types of friction: "rolling friction" and "sliding friction." These types of friction significantly affect the efficiency and lifespan of the bearings. We will explain how Nanopump® technology can help reduce these two forms of friction.

2). Fig. 4 illustrates the main areas where friction occurs within the bearing. R represents "Rolling contact," while S denotes "Sliding contact." Rolling friction occurs when the balls or rollers in the bearing roll, characterized by a low coefficient of friction (0.001 to 0.005). In contrast, sliding friction occurs between the retainer and the inner and outer rings, exhibiting a high coefficient of friction (0.1 to over 1), which can often lead to bearing failure, especially at high speeds.

3). The red line in Fig. 4 indicates the areas where the balls are in contact with the inner and outer ring tracks while rolling, and the black line represents the axis of rotation of the balls. The balls rotate around their axes while also revolving along the track. In areas close to the rotation axis, the contact between the balls and the retainer is a weak sliding contact; however, in the window area of the retainer, strong sliding contact occurs. This creates friction that adversely affects the bearing's performance.

4). Among the sliding contacts, the friction is particularly high in the ball guide section of the retainer. As shown in Fig. 5, when lubrication conditions worsen, excessive stress is placed on the retainer, resulting in the oval-shaped wear indicated in blue. If this wear progresses, it can lead to damage of the retainer and ultimately cause failure of the entire bearing.



R-S : Rolling-sliding contact
S : Sliding contact
S : Intense sliding contact

Fig. 4: The locations where friction occurs inside the bearing

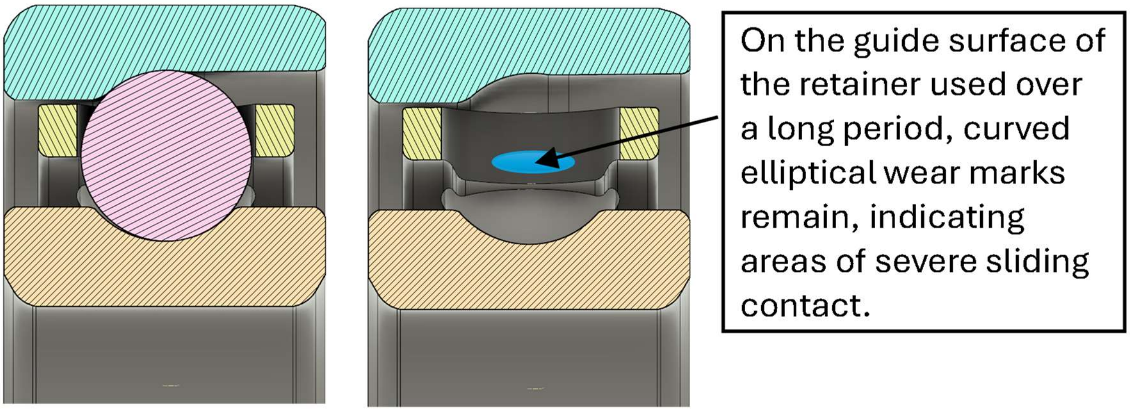


Fig. 5: The ball guide section of the cage with significant sliding friction

5). Here, we present the solution utilizing the Nanopump®. As illustrated in Fig. 6, the nozzle of the Nanopump® penetrates the "air barrier" formed on the side of the bearing and approaches the vicinity of the ball's rotational axis. The nozzle tip is positioned just shy of touching the ball, allowing the lubricating oil to transfer directly to the ball without being affected by the "air barrier."

6). This lubricating oil is spread across the entire surface of the ball through both its rotation and revolution and is distributed to the cage and raceway (indicated in orange in the diagram). This ensures sufficient lubrication in areas prone to friction, effectively reducing friction.

7). The lubricating oil supplied by the Nanopump® nozzle is applied in the area where surface speed is lowest and centrifugal force is minimal, allowing approximately half of the oil to be efficiently used for lubrication. This technology enables the efficient reduction of both rolling friction and sliding friction, maximizing the performance of the bearing.

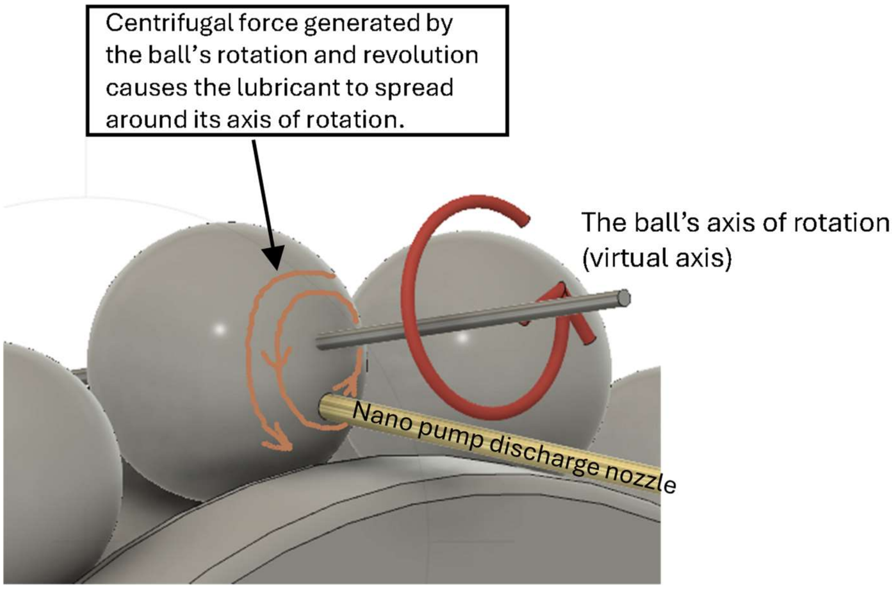


Fig. 6: Mechanism of Nano Lubrication by the Nanopump®

6.Lubrication Effect of the Nanopump®

1). We present the experimental results of applying the Nanopump® to an actual high-speed spindle. In this experiment, we successfully lubricated the bearings with an extremely small amount of oil. The results are groundbreaking, showing a significant performance improvement and waste reduction compared to conventional lubrication systems.

2). As shown in Table 3, the results of the nano lubrication tests are outstanding. In Test No. 1, with 50 nl of oil discharged every 30 seconds, the spindle was lubricated with only 0.006 ml of oil per hour. Furthermore, in Test No. 4, which had the lowest discharge volume, 20 nl of oil was discharged every 120 seconds, resulting in a usage of only 0.0006 ml per hour.

3). In contrast, the discharge rate of commonly used oil-air lubrication systems, as listed in catalogs, typically ranges from 5 ml to 30 ml per hour. Achieving lubrication levels below 1 ml per hour generally requires special arrangements with the manufacturer. Even if we set the minimum discharge rate of the oil-air system at 0.1 ml/h, the Nanopump® demonstrates astonishing efficiency, achieving the same effect with only 1/17 to 1/167 of the oil.

Table 3: Example of High-Speed Rotation Test Results for Nano Lubrication

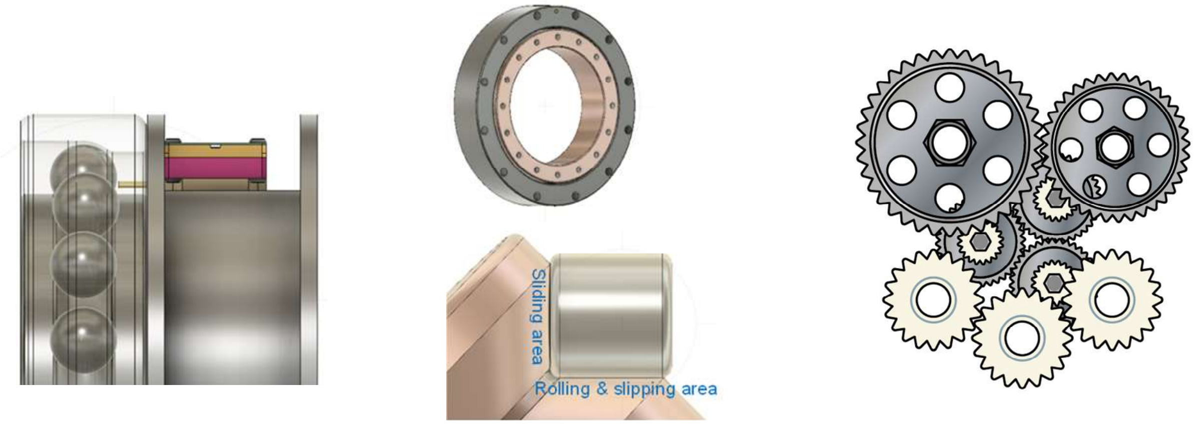
No	Discharge Volume per Cycle nl	Discharge Interval s	1 Hour Discharge Volume: ml (Ratio to 0.1 ml/hr)	Annual Discharge Volume ml	Front Bearing	Rear Bearing	Rotational Speed rpm
1	50	30	0.006 (1/17)	52.56	7008	7006	20,000
2	50	40	0.0045 (1/22)	39.42	7008	7006	20,000
3	45	120	0.00135 (1/74)	11.826	7008	7008	40,000
4	20	120	0.0006 (1/167)	5.256	7008	7008	40,000

4). Based on the above results, it has been demonstrated that nano lubrication using the Nanopump® not only overcomes the "air barrier" issue that has been a challenge for conventional oil-air lubrication systems but also significantly reduces the amount of lubricating oil required. This technological innovation is expected to lead to cost reductions, and a lower environmental impact compared to traditional lubrication methods, paving the way toward a more sustainable future.

7. Potential for Expanding Applications of Nanopump® Technology

1). By applying Nanopump® technology to grease lubrication, significant advantages can be anticipated, including: (i) reduced torque, (ii) decreased noise levels, (iii) suppression of temperature rise, and (iv) enhanced speed. These improvements could lead to better performance in various aspects.

2). This Nanopump® technology is not limited to the spindles of machine tools but is also applicable to other bearings and diverse mechanical devices. In particular, by utilizing it in systems involving rotating equipment and where sliding friction is a concern, further enhancements in energy efficiency and sustainability can be expected. The Nanopump® will play an increasingly important role as an innovative solution to lubrication challenges in all types of rotating machinery.



Rolling bearings Crossed roller bearings Transmission gear

Fig. 7: Applicability of the Nano Pump®