Journal of HyoJeong Academia

Article

A Prognostic Inspection and Proactive Maintenance System (PIPM) to Bring Snowball Effects on the Transition to the Circular Economy and a Carbon-Neutral Society

Junhyong Kim[1], Inho Cho[1] and Youngsik Pyun[1,*]

[1]DesignMecha Co., Ltd., Asan, 31460, Korea
*Correspondence: yspyoun@gmail.com

Abstract: The Sustainable Development Goals (SDGs) of the United Nations and the international community are consist of 17 goals and 169 specific goals and aim to solve the global poverty problem and realize sustainable development between 2016 and 2030. No poverty, Zero hunger, Good health and well-being, Quality education, Gender equality, Clean water and sanitation, Affordable and clean energy, Decent work and economic growth, Industry, innovation and infrastructure, Reduced inequalities, Sustainable cities and communities, Responsible consumption and production, climate action, Life below water, Life on land, Peace, justice and strong institutions, Partnerships for the goals are the 17 goals. Transitioning to the Circular Economy and a Carbon-Neutral Society could be the main structure to realize these SDGs. A Prognostic Inspection and Proactive Maintenance System (PIPM) of rolling bearings can renew service life repetitively by about three times and thus it could be an innovative solution to change rolling bearing supply chain. The PIPM system of rolling bearings will be a good solution to realize a circular economy system and to reduce CO2 emission significantly. One ton of bearings of the PIPM system can save more than 20 tons CO2 emissions. The PIPM system could be applied to mechanical components which need replacement repetitively due to fatigue stress and so it could bring snowball effects on the transition to the Circular Economy and a Carbon-Neutral Society.

Keywords: Prognostic Inspection and Proactive Maintenance (PIPM) System, Circular Economy, Carbon-Neutral Society, Restoration

Citation: Junhyong Kim, Inho Cho and Youngsik Pyun. A Prognostic Inspection and Proactive Maintenance System (PIPM) to Bring Snowball Effects on the Transition to the Circular Economy and a Carbon-Neutral Society. *JHJA* **2023**, 2.

Received: 27 September 2023
Accepted: 28 December 2023
Published: 31 December 2023

Publisher's Note: JHJA stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

1. Introduction

Succeeding of the Millennium Development Goals of the United Nations which were launched in 1983, the 17 Sustainable Development Goals (SDGs) of the United Nations were formulated in 2015 by the United Nations General Assembly. The 17 goals and 169 specific targets are to solve the global poverty problem and realize sustainable development between 2016 and 2030. No poverty, Zero hunger, Good health and well-being, Quality education, Gender equality, Clean water and sanitation, Affordable and clean energy, Decent work and economic growth, Industry, innovation and infrastructure, Reduced inequalities, Sustainable cities and communities, Responsible consumption and production, Climate action, Life below water, Life on land, Peace, justice and strong institutions, Partnerships for the goals are the 17 goals. The Division for Sustainable Development Goals (DSDG) in the United Nations Department of Economic and Social Affairs (UNDESA) acts as the Secretariat for the SDGs, and the United Nations Office for Sustainable Development (UNOSD) was established in 2011 in Incheon, the Republic of Korea [1, 2]. Francesco Fuso Nerini et al showed in their study that climate change can undermine 16 SDGs, while combatting climate change can reinforce all 17 SDGs but undermine efforts to achieve goal 12 (Responsible consumption and production) [3].

The objective of the IPCC (Intergovernmental Panel on Climate Change), which was created in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), is to provide governments at all levels with scientific information that they can use to develop climate policies. IPCC reports are also a key input into international climate change negotiations [4]. Nationally determined contributions (NDCs) are the Government decisions and actions for reducing the total greenhouse gas emissions (mainly CO2 emissions) following the Paris Agreement. The final goal of the IPCC is to realize net-zero emission and is in line with "Climate action' of the SDGs.

The definition of the Circular Economy is "A production and consumption model which involves reusing, repairing, refurbishing and recycling existing materials and products to keep materials within the economy wherever possible. A circular economy implies that waste will itself become a resource, consequently minimizing the actual amount of waste. It is generally opposed to a traditional, linear economic model, which is based on a 'take-make-consume-throw away' pattern". The European Union introduced its vision of the circular economy in 2014 and made the Circular Economy Action Plan in 2021, in which scaling up the circular economy from front-runners to the mainstream economic players will make a decisive contribution to achieving climate neutrality by 2050 and decoupling economic growth from resource use, while ensuring the long-term competitiveness of the EU and leaving no one behind. 11 goals among 17 SDGs have a significant relationship with the Circular Economy in the EU [5]. Therefore, transitioning to the Circular Economy and a Carbon-Neutral Society could be the main structure to realize these SDGs.

A Prognostic Inspection and Proactive Maintenance System (PIPM) is an integrated system of surface modification Technology and non-destructive inspection technology of surface characteristics with remanufacturing system. General Preventive Maintenance (PM) is the practice of performing regular and routine maintenance on machines and equipment to prevent breakdowns and ensure optimal performance. In the case of the PM, maintenance or replacement of parts is absolutely necessary after a certain period of time. However, in the case of the PIPM, the service life is predicted through prior inspection and the service life of the entire product is improved by applying UNSM technology to the relevant parts. PIPM could be a new concept of remanufacturing technology in the circular economy and bring snowball effects on the Transition to the Circular Economy and a Carbon-Neutral Society.

2. Prognostic Inspection and Proactive Maintenance for Rolling Bearings

The concept of the Prognostic Inspection and Proactive Maintenance Program for Rolling Bearings as an extension of remanufacturing was proposed in 2019 as Fig. 1 [6].

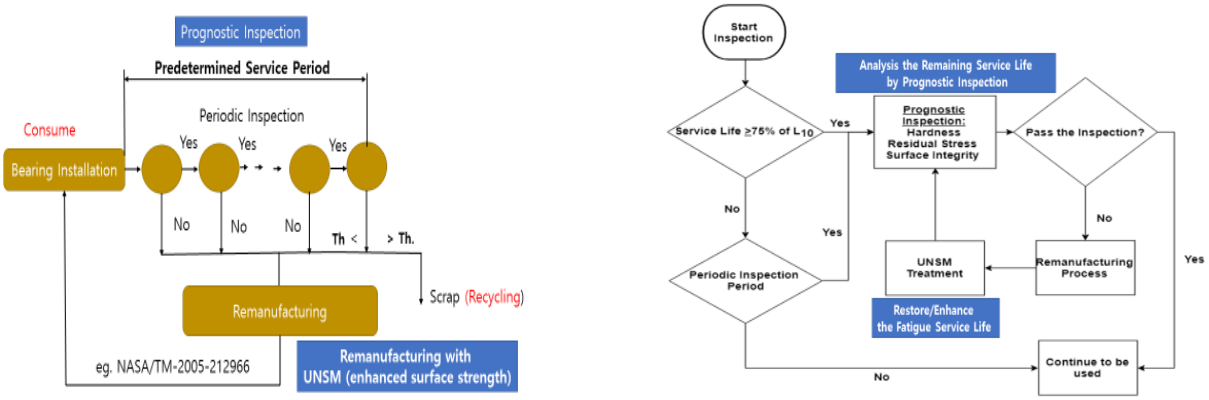


Figure 1. Concept of PIPM (Prognostic Inspection and Proactive Maintenance) for Rolling Bearings.

Remanufacturing of rolling bearings is a well-known methodology not only for saving materials and energy but also for reducing down time of production in aircraft operation, steel mill operation, train operation, etc. Periodic inspection, maintenance and remanufacturing are common practices and the detailed practice for aircraft bearings and train bearings was developed as a standard manual [7, 8].

Built-up fatigue stress in terms of rolling contact fatigue stress and rotary bending fatigue stress could be restored by UNSM (Ultrasonic Nanocrystal Surface Modification) and so the service life could be even enhanced more than the original service life of a new one [9]. Application results in steel mill operation showed a very good compromise to research results of test specimens [10].

Remanufacturing applications of large size bearings for steel industry showed that the service life of remanufactured bearings together with ultrasonic surface modification (UNSM) was and even improved more than new ones. The lifespan of remanufactured bearings using UNSM technology was improved by more than 107% compared to new bearings [10]. The reason why the restored service life was more than or equal to new ones was the improved surface roughness and surface hardness and increased compressive residual stress which were the effects of UNSM [11]. Additionally, friction and wear characteristics were improved due to the formation of micro dimples.

The UNSM technology itself is a kind of green technology which uses only Max. 1.5 Kw power consumption. But it could induce severe plastic and elastic deformation on the surface up to 1,100um depth by applying up to 30 Giga Pascal dynamic pressure with up to 2.4 million times strikes per minute. The main concepts and effects of UNSM are explained in Fig. 2 [12-15].

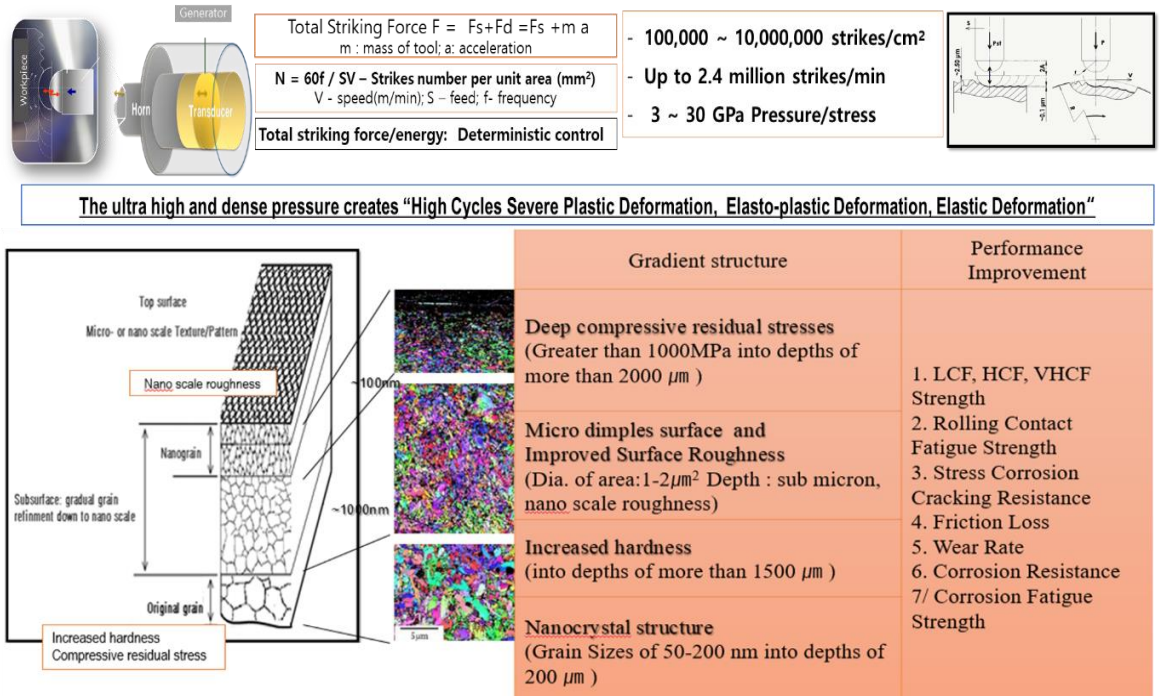


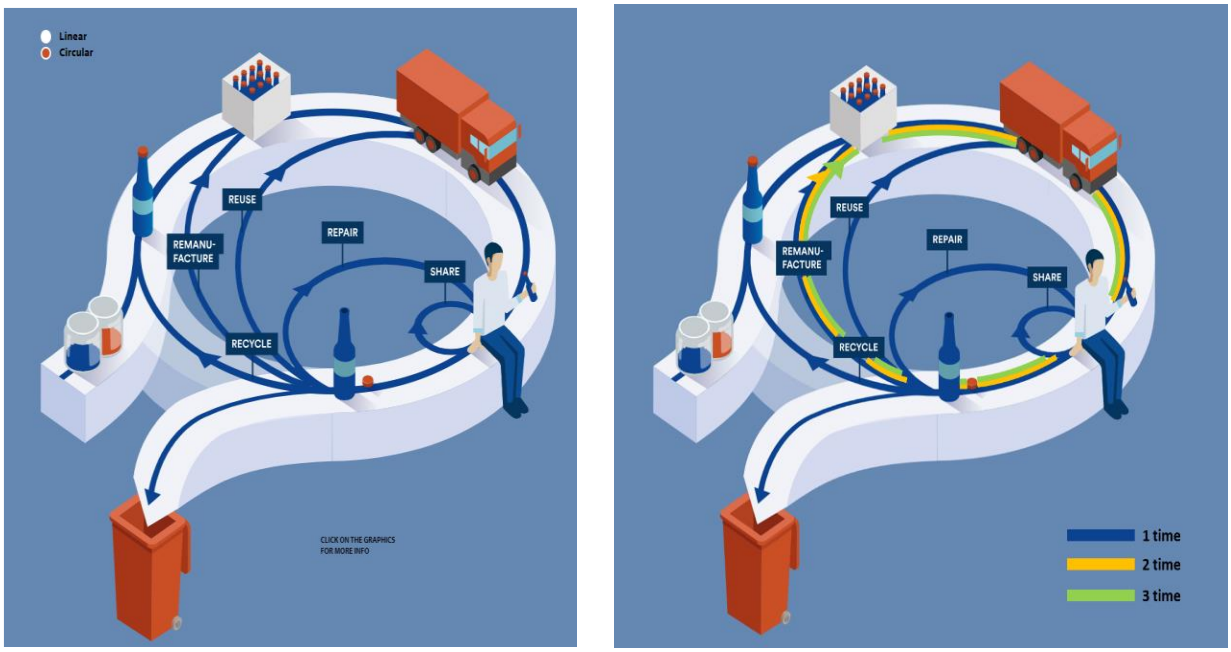
Figure 2. The concepts and effects of UNSM technology.

Prognostic Inspection is constituted with nondestructive inspection technology such as surface roughness tester, surface hardness tester and compressive residual stress testers. Some typical testers are as shown in Fig. 3. The inspection period and test methodology with decision criteria should be determined according to the bearing specification and operation environments. Artificial Intelligence technology such as neural net and machine learning could derive a good solution for prognostic inspection and UNSM process parameters.

(a) **(b)** **(c)**

Figure 3. Typical testers for prognostic inspection: (a) Surface roughness tester; (b) Surface hardness tester; (c) Surface residual stress tester.

When PIPM system is adopted to supply chain in Circular Economy, the number of possible remanufacturing trial could be more than 3 times as shown Fig. 4. But the numbers should be verified by the rigorous reliability study and test.



(a) **(b)**

Figure 4. Improved Circular Economy with PIPM system: (a) Current Circular Supply Chain; (b) PIPM Circular Supply Chain.

Conventional remanufacturing processes could reduce the purchasing cost by about 35% and lead time about by 50%. A PIPM system with a remanufacturing process could reduce the purchasing cost by another 5%. In addition, remanufacturing methods using UNSM technology are being studied in the additive manufacturing field [16]. But more important effects are saving raw materials and energy and reducing CO2 emissions. Carbon intensity of steel is 2~4, which is the CO2 output in tons per steel 1 ton production.

Typical large size bearings for the hot rolling line in the steel industry have 1 ton weight. The buy to fly ratio of the forging and machining process of bearings is about 16:1, which means 16 tons of raw steel are needed to produce 1 ton product [17-19]. So a PIPM system with a remanufacturing process of 1 ton bearing can save about 32 tons CO2 emissions.

3. Discussion and Concluding Remarks

The current price of CO2 emission savings per ton is $50, but the IPCC estimated that it could be increased up to $100. So when 96 times of saving is approved, a 1 ton of PIPM system with a remanufacturing bearing process could be valued at about $48,000 to 96,000. So it is already 2.5~5.6 times the price of new bearings, because the average price of 1 ton bearings is $17,000 [20].

Annual production of bearings in the world is about 7 million tons. So it is not difficult to adapt 10% of bearings in the PIPM system with a remanufacturing process. The annual savings of total CO2 emission could be reach up to 67.2 million tons ($3.36 ~ 7.72 billion). This is almost 9.2 % of Korea NDC reduction target 727.6 MtCO2eq by 2030 [21].

A PIPM system could be expanded to any kinds of metal components which need periodic maintenance in order to restore their fatigue service life like snowball effects. Then their expected savings could become several hundred times in bearings. Typical industries are the electric power industry, the aerospace industry including the airway industry, the chemical industry, the gas and oil industry, the shipbuilding industry, etc.

Nevertheless, the total sum of savings looks huge and good enough to shift to adopting a PIPM system with a remanufacturing process. When we consider a typical Korean steel manufacturers who is uses about 4,000 tons of bearings, their savings and benefits are about 38,400 tons of CO2 and $1,920,000~3,860,000 respectively. This

amount of financial benefit is not a considerable motivation for the operation engineer or manager to adopt this system.

Policies like carrots (eg. financial benefits) and sticks (eg. mandatory usage rate) to adopt a PIPM system with a remanufacturing process should be introduced. Especially the application of PIPM systems with a remanufacturing process should become a top priority of policies and cultures in industry and society.

References

1. THE 17 GOALS, Sustainable development. https://sdgs.un.org/goals (accessed on 01 August 2023).
2. Sustainable Development Goals. https://en.wikipedia.org/wiki/Sustainable_Development_Goals (accessed on 01 August 2023).
3. Fuso Nerini, F. et al. Connecting climate action with other sustainable development goals. *Nat Sustain 2*, 674–680 (2019).
4. About the IPCC. https://www.ipcc.ch/about (accessed on 01 August 2023).
5. Rodríguez-Antón, J. et al. From the circular economy to the sustainable development goals in the European Union: an empirical comparison. *Int Environ Agreements 22*, 67–95 (2022).
6. Darisuren, S. et al. A Proposal of prognostic inspection and proactive maintenance program for rolling bearings. In Proceedings of the 5th International Conference on Materials and Reliability, Jeju, Korea (27-29 November 2019).
7. Zaretsky, E. and Branzai, E. Effect of rolling bearing refurbishment and restoration on bearing life and reliability. *Tri-bol Trans 48*(1), 32-44 (2005).
8. AAR. *Manual of Standard and Recommended Practices Section H - Part II* (AAR, 2000).
9. Kim, J., Pyun, Y. and Kayumov, R. Bearing fatigue layer restoration by application of micro cold forging technology. In Proceedings of the KSME, Changwon, Korea (7~9 November 2012).
10. Darisuren, S. et al. Remanufacturing process and improvement in fatigue life of spherical roller bearings. *Journal of KSTLE 30*(6), 350-355 (2014).
11. Cho, I., Darisuren, S. and Kim, J. Development of remanufacturing technology for large industrial bearings and analysis of the sustainable economic impact. In Proceedings of the 1st International conference of Hyojeong Academy, Asan, Korea (27-29 January 2023).
12. Nagaraja, K. et al. Multiphysics modeling of in situ integration of directed energy deposition with ultrasonic nanocrystal surface modification. *The International Journal of Advanced Manufacturing Technology 120*, 5299-5310 (2022).
13. Chang, S., Pyun, Y. and Amanov, A. Wear enhancement of wheel-rail interaction by ultrasonic nanocrystalline surface modification technique. *Materials 10*(2), 188 (2017).
14. Kim, M., Park, S., Pyun, Y. and Shim, D. Optimization of ultrasonic nanocrystal surface modification for surface quality improvement of directed energy deposited stainless steel 316L. *Journal of Materials Research Technology 9*(6), 15102-15122 (2020).
15. Karimbaev, R., Pyun, Y. and Amanov, A. Fatigue life extension of additively manufactured Nickel-base 718 alloy by nanostructured surface. *Materials Science & Engineering A 831*, 142041 (2022).
16. Li, W. et al. Processing aluminum alloy with hybrid wire arc additive manufacturing and ultrasonic nanocrystalline surface modification to improve porosity, surface finish, and hardness. *Journal of Manufacturing Processes 103*, 181-192 (2023).
17. Pierrat, E., Rupcic, L., Hauschild, M. and Laurent, A. Global environmental mapping of the aeronautics manufacturing sector. *Journal of Cleaner Production 297*, 126603 (2021).
18. Barnes, J., Kingsbury, A. and Bono. E. Does "Low cost" Titanium Powder Yield Low Cost Titanium Parts? In Proceedings of the International Conference on Powder Metallurgy, Boston, USA (5~8 June 2016).
19. Branger, F., Quirion, P. and Chevallier. J. Carbon Leakage and Competitiveness of Cement and Steel Industries Under the EU ETS: Much Ado About Nothing. *The Energy Journal 37*(3), 109-135 (2016).
20. Carbon Pricing. https://www.worldbank.org/en/results/2017/12/01/carbon-pricing (accessed on 01 December 2017).
21. Submission under the Paris Agreement: The Republic of Korea's Enhanced Update of its First Nationally Determined Contribution. https://unfccc.int (accessed on 23 December 2021).