WEAR PROTECTION: THE KEY TO LONG-TERM SUSTAINABILITY

The World Commission on Environment and Development (WCED) of the United Nations defined in 1987 sustainability as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs," meaning that resources should be consumed at a rate that still allows to make them available in equal quality and quantity to further generations [1]. The current climate crisis can be attributed to unsustainable emissions of CO_2 and other greenhouse gases into the atmosphere at a rate greater than photosynthetic capture. With increasing awareness of this problem, governments have issued many policies and regulations that require industries to adopt more sustainable practices and limit their carbon footprint [1]. One such method of reducing carbon footprint and improving sustainability is to increase longevity by reducing wear between moving parts [2]. Reducing friction and wear can contribute to less energy loss to heat and excessive movement, fewer necessary part replacements, and longer overall machine life. Because of the many benefits of reducing friction, there have been growing efforts to study friction and explore more sustainable practices.

The resource issue has so far been subordinate to the CO_2 issue. In 2017, humanity consumed 92.1 gigatons of resources, followed by 8.6 gigatons of cycles sources [3]. The material streams going into applications and end-uses in relation to tribosystems ranged from 9.1 to 17.7 gigatons [3]. The mining, extraction and processing of primary metals/material inevitably emits greenhouse gases, where the average ratio of one ton of primary metal or material to CO_2 emissions in 2018 ranged between 1.38 to 1.82 tons of CO_2 [3]. However, tribology plays a big role in reducing CO_2 emissions by improving wear protection that enhances the longevity of tribosystems. Longevity can be increased (or doubled) by means of wear protection, condition monitoring, tribotronics or maintenance, repair or overhaul (MRO). By utilizing the appropriate wear protection methods that can double the general service life of the systems, more than 8.8 gigatons of resources can be conserved [3]. Overall, the medium and long-term reduction potentials by wear protection are at least more than 6 gigatons CO_2 or 16% of the globally emitted 37.9 gigatons of CO_2 emitted directly in 2019 [3]. However, to determine the proper wear protection methods, fundamental knowledge surrounding the engineering and science of any operation is important in optimizing machinery and minimizing both energy loss as well as component and part replacements [3].

Figure 1 summarizes how mechanical systems can operate at an optimized state through the use of FLAB (Fasteners, Lubrication, Alignment and Balance), which is directly associated with wear protection and friction management [2].

Generally, shaky, noisy, hot, and dirty machines are known to be very inefficient, unreliable and release a large amount of waste while smooth, quiet, cool, and clean machines are optimal with regards to energy waste [2]. A machine can be optimized by

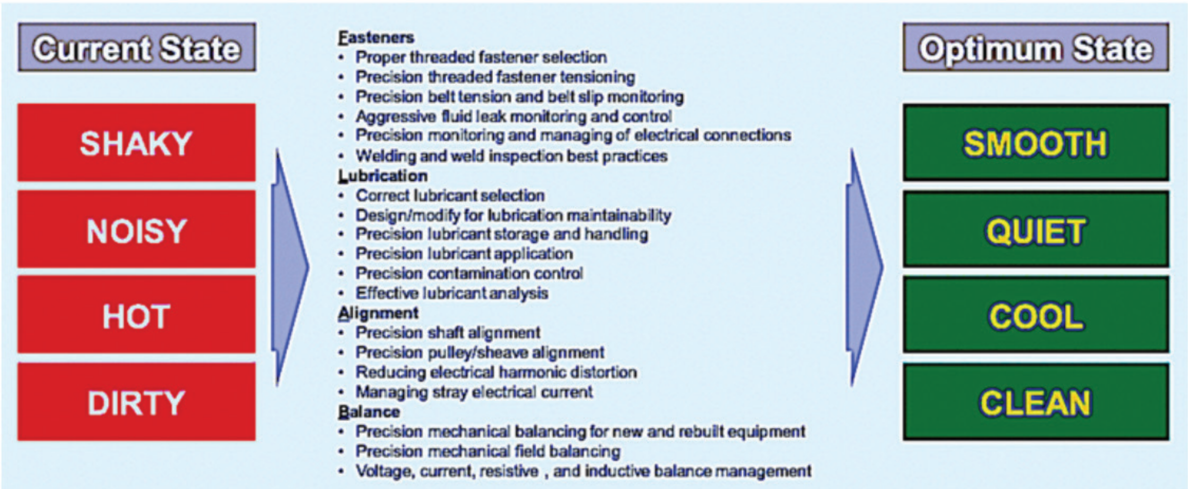


Figure 1. Wear protection and friction management of mechanical systems through FLAB (fasteners, lubrication, alignment and balance) [2]

current implementation of FLAB [2]. Areas of improvement to lessen vibration and reduce friction include structural integrity from correct mechanical fastening techniques; proper selection, application, and management of lubricants and hydraulic fluids; precise shaft and pulley alignment; and mechanical and electrical balance [2]. As such, smooth and long-lasting operations can be achieved by improving FLAB to not only bring down energy consumption and operating costs but also increase the reliability and productive output of machinery. The application of better wear protection and friction management of these systems has great potential in environmental and economic sustainability, reducing energy consumption and global carbon emissions and increasing the longevity of resources [5].

After recognizing the significance of wear protection and friction management, researchers have developed innovative designs for components such as fasteners, lubricants and additives, new materials, and coatings for surface engineering (surface treatments, modifications and texturing) [2]. Lubrication is especially essential in any operation for decreasing friction and wear between sliding surfaces, minimizing direct surface contact, and reducing power requirements [6]. Most lubricants are liquids, composed of oil and additives, with some gaseous and solid exceptions. One study investigated three types of lubricants and their effects on friction and torque-tension relationships in threaded fastener applications [5]. This research specifically examined the application of oil, grease, and soil film lubricants to the threads of the fastener and the nut, the turning bolt underhead surface, and the joint surface in contact with the bolt head (Figure 2) [6]. This area of research is important because an estimated 90% of the torque needed to tighten an unlubricated bolt is consumed in overcoming friction, leaving only 10% of the energy transformed into actual work [6]. The study observed that the greases and oil have similar friction behavior while the solid film lubricants produce the lowest thread and head bearing friction [5]. However, lower friction coefficient lubricants are not suitable for all machines. For instance, if the friction coefficient is too low, clutches in hydraulic systems can fail and pose a major safety hazard [5]. Before selecting the most appropriate lubricant, a system needs to be defined accordingly. Important parameters include the type of motion, speed, temperature, load, and operating environment of the system, as well as the geometry and shape of the machine the lubricant is acting on [6].

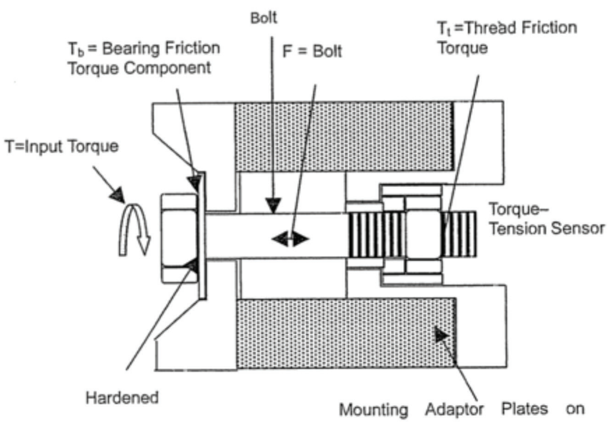


Figure 2. Experimental set up of fastener machine [5]. This machine tightened the fastener while measuring torque and tension to calculate friction.

The most effective anti-wear and extreme pressure additives are based sulfur, phosphorus, as well as zinc and molybdenum, as well as other environmentally critical compounds [6]. Additionally, ecological concerns arise not only during the use of lubricants, but when they are drained, dumped or spilled into waters and soils [8]. Therefore, various studies have considered alternatives such as bio-lubricants for their biodegradable and eco-friendly characteristics. Bio-lubricants can actually have good lubricity, high flash point, high viscosity index, and good resistance to shear. However, the market penetration of bio-lubricants is still limited due to their high costs and lack of policies apart from the second issuance of U.S. Vessel General Permit for water-sea interfaces [9]. Environmentally acceptable lubricants (EALs) meet the expectations of United Nations sustainable development goals (SDGs) #3.9, #6.3 und #12.4 [7].

In addition to lubricants, another method to improve wear protection is through component surface modifications, mainly by increasing the hardness. Wear resistant materials and coatings can substitute anti-wear and extreme pressure additives in lubricants and thus facilitate to meet the different ecotoxicological criteria. Depending on the chemical composition and its particular application, there are various viable coating techniques such as thermal spraying, chemical vapor deposition (CVD), and physical vapor deposition (PVD) [9]. Known for their low-friction coefficients and wear resistances, diamond-like carbons (DLC) are deposited on tappets, camshafts and piston rings to improve fuel efficiency and engine longevity [6]. Surface modification techniques such as hardfacing and surface coating are cost-effective methods that can improve the wear resistance of materials, extending service life, decreasing maintenance costs, and overall improving sustainability [9]. Component surface modifications are also common in engines involving a piston ring-cylinder liner, valve trains and fuel injection systems [6]. Especially in the automotive sector where wear is a common issue, surface coating is known to be an efficient method for wear protection. The automotive sector is one of the major consumers of energy that contributed greatly to carbon emissions. Therefore, the implementation of surface coatings to reduce friction and improve efficiency can have a significant impact on carbon emissions and the climate crisis.

Friction and wear protection are linked together through their contributions to greenhouse gas emissions. Since sustainability requires lower consumption and less waste of both energy and raw materials, more emphasis is being placed on discovering methods and technologies to improve longevity and reduce the friction of the machinery within a process. Advances in innovative component designs, lubricants and additives, and component surface modifications have valuable contributions in this field. By optimizing these components in various combinations based on system specifications, engineers can work to keep frictional energy loss and mechanical wear as low as possible.

References:

[1] United Nations, "Transforming our world: the 2030 Agenda for Sustainable Development", resolution adopted by the General Assembly", 2015, https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_RES_70_1_E.pdf

[2] Troyer D., "Look to Tribology to Reduce Climate Change Impact", The RAM Review, 2020

[3] Woydt, M., "The importance of tribology for reducing CO_2 emissions and for sustainability". WEAR 474–475, 2021, DOI: 10.1016/j.wear.2021.203768

[4] Shah R., Woydt M., Huq N., Rosenkranz A., "Tribology meets sustainability", Industrial Lubrication and Tribology, 2020, DOI: 10.1108/ILT-09-2020-0356

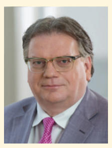
[5] Zou Q., Sun T S., Nassar S., Barber G., "Effect of Lubrication on Friction and Torque-Tension Relationship in Threaded Fasteners", Tribology Transactions 50, 2007,1,127-136, DOI: 10.1080/10402000601105490

[6] Hassan M., Zulkifli S A., Hasnul H., Yusoff A., "Tribological advancement - strategies and effects towards emissions and global energy consumption", IMIEC, 2018, DOI: https://doi.org/10.1051/matecconf/201820400003

[7] Shah R., Woydt M., Zhang S., "The Economic and Environmental Significance of Sustainable Lubricants". Lubricants 2021,9,21. https://doi.org/ 10.3390/lubricants9020021

[8] Somers A., Howlett P., MacFarlane D., Forsyth M., "A Review of Ionic Liquid Lubricants", Lubricants, 2013,1;3-21, DOI: 10.3390/lubricants1010003

[9] Shibe V., Chawla V., "A Review of Surface Modification Techniques in Enhancing the Erosion Resistance of Engineering Components 1", International Journal of Research in Mechanical Engineering & Technology, 2014,4;2;92-95



Dr. Mathias Woydt is managing partner of MATRILUB Materials Tribology Lubrication, with more than 34 years of experience in R&D and with more than 340 publications and 51 priority patents filed. STLE Fellow, recipient of ASTM award of excellence and board member of the German Society for Tribology. He can be reached at m.woydt@matrilub.de

Ms. Joceline Gan is part of a thriving internship program at Koehler Instrument company and a student of chemical engineering at State University of New York, Stony Brook, where Dr. Shah currently heads the External advisory board of directors.

Mr. Karthik Ledallais part of a thriving internship program at Koehler Instrument company and a student of biomedical engineering. He is also the current president of New York Omicron chapter of Tau beta Pi, the preeminent engineering honor society

Dr. Raj Shah is a Director at Koehler Instrument Company in New York, where he has worked for the last 25 years. He is an elected Fellow by his peers at IChemE, CMI, STLE,

AIC, NLGI, INSTMC, The Energy Institute and The Royal Society of Chemistry An ASTM Eagle award recipient, Dr. Shah recently coedited the bestseller, "Fuels and Lubricants handbook", details of which are available at https://www.astm.org/DIGITAL_LIBRARY/MNL/SOURCE_PAGES/MNL37-2ND_foreword.pdf

A Ph.D in Chemical Engineering from The Penn State University and a Fellow from The Chartered Management Institute, London, Dr. Shah is also a Chartered Scientist with the Science Council, a Chartered Petroleum Engineer with the Energy Institute and a Chartered Engineer with the Engineering council, UK. An adjunct professor at the Dept. of Material Science and Chemical Engineering at State University of New York, Stony Brook, Raj has over 380 publications and has been active in the petroleum field for 3 decades. More information on Raj can be found at https://www.petro-online.com/news/fuel-for-thought/13/koehler-instrument-company/dr-raj-shah-director-at-koehler-instrument-company-conferred-with-multifarious-accolades/53404

Author Contact Details

Dr. Raj Shah, Koehler Instrument Company • Holtsville, NY 11742 USA • Email: rshah@koehlerinstrument.com • Web: www.koehlerinstrument.com