Power Struggle: Applying surface engineering to meet today's energy demands

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Developing new ways to meet the projected two per cent annual increase in global energy demand presents a challenge for all aspects of science and engineering. The consumption of natural resources, coupled with increasing legislation to reduce carbon dioxide emissions, mean the requirement for more efficient power generation has never been greater.

Optimisation of energy generation is closely linked to the study of surface friction and wear because potential energy of various forms is converted to useful mechanical energy – rotation of an electricity generating turbine or the piston in an internal combustion engine. This involves sliding or rolling contacts between interacting surfaces. Minimising friction is crucial in terms of efficiency and reducing power losses, however, component lifetime also needs to be considered, as unexpected downtime to repair or replace worn out parts is costly.

Economic impact

The potential economic impact of tribology in relation to energy consumption was first revealed in the Jost Report produced by a Committee of the British Department of Education and Science in 1966. It proposed the British economy could save one per cent of its gross national product per year by addressing losses from frictional energy dissipation due to poor lubrication and downtime from component repair. These issues remain pertinent today, with further optimisation the goal, especially in the face of legislation to reduce greenhouse gas emissions.

The approach of engineers in recent years has been holistic – designed to look at all aspects of the manufacture, operation and lifecycle of components subject to sliding contacts – in order to facilitate the optimum solution for the specific requirement. Friction and wear are not the only factors considered – cyclic loading and fatigue are equally essential for the longevity of operation.

Bearing up

For modern power generating machinery such as steam, gas and hydroscheme turbines, it is necessary to understand the complex loading cycles on the shaft bearing contacts associated with the rotational velocity and modal vibration. These can affect lubricant film thickness and, therefore, the friction and wear properties. This is vital as degraded performance can result in synergistic effects on other rotating components, potentially causing blade casing or seal rubbing, which can add to further vibration and premature failure of the turbine.

Advances in lubricant chemistry have been complemented by the advent of surface engineering technologies, which allow deliberate manipulation of the contacting face of materials. Lubrication is critical to the maintenance of separated surfaces, but often when the possibility of contact does exist, such as during the start-up of a gas turbine, a layer of low melting point white metal or arc spray chromium can provide sufficient protection of the underlying bearing material from damage.

Turbine blades have been the subject of intense research to modify their surface properties to better cope with increased shaft speed and temperatures. Resistance to erosion caused by combustion products and foreign object damage needs to be balanced against factors such as thermal fatigue and oxidation resistance.

New coatings such as thermally sprayed ceramics have successfully been used as protective barriers on combustor cans, ductwork, platforms and, more recently, turbine aerofoils. New developments have seen the introduction of electron beam physical vapour deposition thermal barrier coatings, interfaced by suitable oxidation resistance bond coats (such as the metal-CrAlY system). These exhibit more strain-tolerant columnar microstructures which have good substrate adhesion and improve erosion resistance.

Gale force

There has been a significant growth in the use of wind energy over the last decade, both onshore and offshore. To achieve maximum energy conversion from wind to electricity, horizontal-axis turbine blades and towers have increased in scale, to over 100m for the latter, which brings a new area of specific tribological issues.

Structural flexure of blades as a result of wind loads is not fully understood, and cyclic stresses imposed as a result of the orbital velocity are transferred to the shaft and bearings. Lubricant films, necessary to separate the contact surfaces, have to deal with a combination of low speed, high load and shaft oscillation. Most premature failures of wind turbines, especially those offshore, are mainly due to problems associated at the gearbox. While carburising is the main treatment method for wind turbine gearboxes, advances such as plasma nitriding and nitrocarburising have also been considered.

Research is aimed at scaling up conventional metal-metal bearings for high-load low-speed operation and is looking at contact conditions. The use of new materials and coatings such as ceramic-metal hybrid bearings could find potential application, both here and in other condition specific uses. Online condition monitoring techniques for this new generation of bearings is the subject of research and is providing insights into the wear and lifetime of these components.

Feeling the benefit

Operation of wind turbines in more extreme climates brings problems such as ice formation, insect fouling or sand erosion, causing roughening of the surface of the blade. This changes the air flow and causes drag, leading to vibration and unpredicted energy losses. Although mechanical cleaning is perhaps the simplest method to remedy the problem, this involves downtime of the turbine and makes preventative surface engineered coatings an attractive option.

Low-friction, non-stick elastomeric tapes are often applied to the leading edge of the blade, however, these often need replacing, particularly in the case of erosive wear, as they do not always succeed in absorbing all the energy of impact. Current research favours nanocomposite coatings that exhibit mechanical erosion resistance and low wetting hydrolphilic behaviour, however, these are still in development.

Turning the tide

A new approach of surface engineering related to marine energy production is the issue of organic biofouling. Tidal turbines are continually immersed in sea water and, as static structures, can attract marine organisms which attach to the surface. It is unclear if the tidal flow velocity and associated shear stresses are high enough to remove films, which also result in frictional drag and loss of power.

One way to avoid biofouling is to paint surfaces with a suitable coating that is marine friendly and does not release harmful toxins. Research is looking to optimise polymer coatings with chemicals drawn from natural product extracts. The correct application of engineering to determine the optimal contact conditions, materials and lubrication has the potential to give energy savings, such as those arising from new optimised roller bearings from SKF, which can be up to 30% more efficient than traditional designs. As industrial and consumer energy demands continue to increase, the understanding of energy specific tribology will gain in importance to maintain the effective use of natural resources.