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Case study

Abrasive wear based predictive maintenance for systems operating in sandy conditions

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ABSTRACT

Machines operating in sandy environments are damaged by the abrasive action of sand particles that enter the machine and become entrapped between components and contacting surfaces. In the case of the military services the combination of a sandy environment and the wide range of tasks to be fulfilled results in extreme and uncertain operating conditions. All of this hinders the ability to establish efficient maintenance strategies prior to deployment and increases the risk of mechanical failure. To prevent such problems, it would be desirable to perform maintenance based on the prevailing condition of both the components and the environment. By monitoring the loading situation as well as the characteristics of the sand particles, the wear of components is quantified, allowing maintenance to be performed when necessary.

The development and implementation of such a predictive maintenance concept requires knowledge of the operational and environmental conditions and how they relate to the principal wear mechanisms. Based on previously established relationships between the abrasive particles and the resulting abrasive wear, the current work focuses on the implementation of these results into a predictive maintenance concept for vehicles that operate in a sandy environment. For this, the local parameters that govern the wear mechanism, such as the normal forces and sliding distances need to be linked to machine usage parameters including the type of terrain and the driving distance.

The proposed concept is demonstrated using a case study on the sprockets of a military vehicle, where the sprockets wear progressively during use of the vehicle due to the abrasive action of sand. The predictive maintenance concept is shown to support the determination of maintenance intervals under a range of usage profiles and sand varieties.

1. Introduction

The condition of machine elements deteriorates during use as a result of continuous or repeated mechanical loading. Unwanted phenomena such as wear and fatigue will lead to a reduced operational efficiency and ultimately to failure of the mechanical component and breakdown of the machine. In many situations the breakdown of machinery will result in unplanned standstill which disrupts the primary process, such as a manufacturing process or a means of transportation. In either case, the downtime has a multitude of rather costly consequences and it is therefore common practise to perform timely maintenance, i.e. repairing or replacing a machine's damaged components before failure occurs, thus decreasing the chances of unplanned downtime of the machine. When machines operate under fluctuating conditions the appropriate moment to perform maintenance is hard to predict and generally this uncertainty is dealt with by applying a conservative maintenance interval that is based on the most extreme operational condition for that respective machine. This means that parts are often replaced too early, which is wasteful and expensive. To enable just-in-time maintenance, knowledge is required about the dominant failure mechanisms and the degradation rates of the various components [3]. From the operational conditions the stresses and the related amount of degradation can then be quantified and the remaining lifetime before failure of the component can be estimated. In case of a component that fails due to a wear mechanism, such an approach requires knowledge of the tribological system in which the component operates, comprised of the surfaces in contact, any lubricant (if present) and the operational and environmental conditions.

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Nomenclature

A_c	contact area, mm^2
A_p	projected area of one particle, mm^2
b	half contact width, mm
D	machine life expressed in distance travelled, m
d	wheel diameter, mm
E	Young's modulus, MPa
E'	reduced modulus of elasticity, MPa
F_p	peripheral force, N
F_t	force per gear tooth, N
f	rotational frequency, s^{-1}
f_t	fraction of the total distance travelled in certain terrain, (dimensionless)
f_u	fraction of the total distance travelled on certain uneven surface, (dimensionless)
H	(surface) hardness, N mm^{-2}
k	specific wear rate, mm^3 N^{-1} m^{-1}
K	wear coefficient, (dimensionless)
κ	sharpness of particle
l_{ft}	load factor for terrain pavement, (dimensionless)
l_{fu}	load factor for terrain gradient/unevenness, (dimensionless)
n	feed rate of particles in contact, s^{-1}
N	normal load, N
ν	Poisson's ratio, (dimensionless)
p	packing fraction, (dimensionless)
P	engine power, W
Q	volumetric wear, mm^3
R	Radius, mm
R'	reduced radius, mm
s	sliding distance, m
t	width of a sprocket wheel, mm
T	driving torque, N m
v	driving velocity, m s^{-1}
ω	angular velocity, s^{-1}
Ω	average particle size, μm
z_m	number of gear teeth in contact, (dimensionless)

A typical example of a machine that encounters continuously varying conditions is a military vehicle. These often operate in sandy environments like beaches and deserts and the aggressive nature of the environmental conditions and the worldwide deployment makes these conditions highly variable. Depending on the employment situation such as a training, patrolling or combat, the mechanical loading and the velocities and accelerations at which the machine is used also vary. Furthermore it needs no explanation that, particularly in a combat situation, the consequences associated to premature failure of components of such a vehicle can be dire.

The uncertainty and variability make it difficult to apply a static preventive maintenance concept in which intervals with a fixed length are used. However, particularly during military missions such as in the above sketched example, failure and down-time of the system can be critical and failed components require maintenance as soon as possible. This requires a long-term prediction of the maintenance interval to make sure that spare parts are available when needed.

One way of dealing with this problem is to establish variable maintenance intervals which are based on the actual usage (and associated degradation) of the machine including the driving velocity, the applied motor power and the environment in which the machine has been used. When the instantaneous amount of wear can be quantified and the total amount of wear at failure is known, the remaining lifetime of components can be determined based on the operational and environmental conditions. This enables the timely repair or replacement of the damaged components. This so-called predictive maintenance is increasingly gaining attention [4–7] and is a potential solution for improving the maintenance concept in situations in which the variability of operating conditions prevents the use of a more simple time or mileage based maintenance interval.

Several types of preventive maintenance can be distinguished, where Condition Based Maintenance and Usage Based Maintenance [3] are the most commonly used policies. Both methods monitor the system in order to establish the optimal maintenance intervals, but there is a significant difference as to the focus of the monitoring of these two methods. With condition based maintenance the effects of degradation are monitored more or less directly: the performance and condition of the machine components is measured, such as by employing acoustic methods, by counting the number of particles in the lubrication oil or by applying sensors for measuring the length of cracks in components. Maintenance is scheduled to be performed when the condition of these components has reached a certain predefined critical or threshold level [3]. In contrast, a usage based maintenance policy focuses on measuring and recording the operational conditions of the machine and the condition or degradation of the system is derived from these usage parameters. In its classical form, a usage based maintenance approach focuses on relatively straightforward parameters that can be recorded directly, such as the number of operating hours or the distance travelled, whilst more advanced policies take into account the severity of the usage, which can be defined as a function of the distance and the operational conditions: one operating hour at a high power setting, driving speed or harsh environment can then be accounted for as having a larger contribution to the degradation than one hour of use under milder conditions. This means that in these types of policies the condition of the system is not monitored directly, but the monitored usage parameters are utilised to indirectly, but more accurately, determine the condition of the system [3].

The objective of this paper is to propose a usage based maintenance concept for systems that operate in sandy conditions. In this concept, the severity of the use is quantified using a model that builds on recent experimental and numerical work on the abrasive wear caused by particles [1,2]. The experimental tests and numerical modelling work have resulted in a physical model that can be used to predict the amount of abrasive wear and in the current work this model is implemented into a framework for predictive maintenance. This framework will be demonstrated using a real life case study that concerns a Combat Vehicle 90 infantry fighting vehicle, of which the sprocket wheels are damaged as a result of abrasive wear. The inclusion of a physical model that quantifies the amount of abrasive wear into a predictive maintenance concept is aimed at improving the efficiency of the maintenance procedures on components that are impacted by abrasive wear.

This paper is organised as follows: Section 2 describes the applied method for predicting the abrasive wear rates as a function of the operational conditions. In Section 3 the focus is on a framework for predictive maintenance that is based on general physical models, followed by Section 4, in which the integration of the proposed wear model and the predictive maintenance framework will be discussed, as well as the application to the case study of the CV90 military vehicle. In Section 5 the results of the analysis are presented and discussed, followed by the conclusions.