

# X-GEAR

## DEVELOPMENT OF GEAR DRIVE-TRAINS BASED ON NEW MATERIALS AND NOVEL GEAR SYSTEMS

X-GEAR РАЗРАБОТКА ЗУБЧАТЫХ МЕХАНИЗМОВ НА БАЗЕ НОВЫХ МАТЕРИАЛОВ И СИСТЕМ ЗУБЧАТЫХ КОЛЕС, СОДЕРЖАЩИХ НОВШЕСТВА

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**Abstract:** *The objective of the X-GEAR project is the diffusion and the standardisation of novel technologies and new materials for a new generation of gears characterised by higher accuracy, resistance, reliability, and tribology properties. In this context X-GEAR plays a role in the competitiveness of European industry since aims to comply with the tighter and tighter requirements being put on the gear industry for lighter weight, higher torque transmissions and quieter, more efficient gear trains for the automotive and wind energy sector.*

**KEYWORDS:** gear drive-trains, air-hardening steels, advanced sintered steels, nanopowders, novel surface treatments

### 1. Introduction

The 135.000 European SMEs of the mechanical transmission sector producers of gears and gearing products rely on traditional technologies and are characterised by a general conservatism. However, over the years, the end products in which the gears are used have become more complex and are pushing the state of the art in new technology. Thus the requirement for more sophisticated and reliable gears become extremely important.

In line with the strategic objectives of the associations of manufacturers of gears and mechanical transmission systems, the goal of X-GEAR project is to develop new materials, novel surface treatments for high performances gear drive-trains. X-GEAR is a Collective Research Project (COLL-CT-2006 030433) financed by the European Commission within the framework of the specific research and technological development program "Integrating and strengthening the European Research Area" [1].

Research activities are focused on an innovative combination of new surface treatments, based on Flame and Thermal Spraying, Electron Spark Coating, Physical Vapour Deposition and Laser Shock Peening, with new materials based on nanopowders, new air hardening and advanced sintered steels. In particular the nanopowders which are considered within the project are the detonation diamonds, also called ultra disperses diamond powders (UDDP), with diameter of the particles of the order of 4-6 nanometers (Figure 1). Diamond nanograins are the most abundant but less understood interstellar matter found in meteorites, and astronomical observations suggest that as much as 10 to 20% of the interstellar carbon is in the form of nanodiamonds. Markedly enhanced properties are expected from the exploitation of novel coatings based on UDDP applied on the surface of the gears, including wear resistance (from 2 to 10 times), micro hardness increasing (from 150 to 10000 kg/mm<sup>2</sup>) and increase of corrosion resistance. For an effective transfer of the knowledge



Figure 1: Micropicture of UDDP use of the selected processes and materials, including examples of

generated into the project to the abovementioned industrial sectors, a Design Software Tool and best practices will be developed. The Design tool includes material databases, dealing in particular with UDDP and new steels, and interactive guidelines for the optimal

best practices in the envisaged applications (helical gears for automotive and wind energy sector).

### 2. Prerequisites and means for solving the problem

#### 2.1. Changing needs for mechanical transmission sector

A continuous technological progress can be observed in the machine construction sector for industrial applications. The main requirements for the new generation of machines depend on the application field, but it is generally requested a high reliability, fast and vibration-free operation, accurate positioning, smallest dimensions and economy of use.

The EU has achieved a predominant role at world level in the Mechanical Engineering industry and this is mainly due to the technological excellence of the products produced by EU mechanical engineering companies. It is therefore in the context of maintaining this position of excellence



Figure 2: Microgears

that X-GEAR must be viewed. Mechanical Engineering supplies enabling technology for all parts of the economy and thus is one of the most important and largest industrial sectors of the European Union. For example, as the major supplier of manufacturing equipment and of mechanical parts for the automotive and the wind energy sector, innovation from mechanical engineering companies enables these two strategic industries to constantly reduce costs, increase quality and thus remain competitive.

While the processes still used today for the production of gears rely on consolidated technologies, some of them used for decades, comparing the requirements and gear products of fifty years ago with the components for products in our contemporary high technology world, the difference in both needs and degree of precision is staggering. Over the years the end products in which the gears are used have become more complex and are pushing the state of the art in new technology. Thus the requirement for more sophisticated and reliable gears become extremely important. The gear industry has to implement major changes in gear design and gear fabrication techniques just to keep up with the changing needs of the end product. Moreover, the output of mechanical engineering equipment is growing much faster in China than in the Europe or

USA. China is thus becoming a serious competitor for the European SMEs of the sector.

## 2.2. State-of-the-art and limitations

Today, a large share of the steels used for gears production is medium carbon steels which are hardened and tempered, and sometimes additionally surface induction hardened.

Some European steel makers are developing *new air hardening* avoiding quenching baths, in a manner which significantly can reduce hardening distortion. European steel makers are currently world leading in developing these new steels for bearings and other highly stressed components, but their use in gears has not yet been developed to the point where they could be applied in production. Since these steels will generate different residual stress profiles to conventional case carburised and nitrided gears, techniques need to be developed for generating optimal residual stress profiles in these steels during or after quenching.

The past decades have seen a continuous growth of the use of powder metal (PM) for mass produced high quality components as the automotive sector. However, the performance requirements the components must meet are more and more demanding. Transmission gears for automotive applications are complex in shape and require very high geometrical accuracy in terms of gear quality and also very high mechanical performance in terms of durability [2].

Surface-hardened materials are widely used in the manufacture of high performance gears. Carburizing, nitriding and induction hardening are the most commonly used hardening processes that result in the reduction of macro-pitting which is the main failure mechanism of hardened materials. *Nanostructured materials*, such as diamond-like carbon (DLC), deposited as a coating, can significantly improve the performance of gears. By applying such coatings to existing gear designs, it is possible to significantly extend service life. However, there are significant barriers between today's coating technology and these goals. First, the processes for depositing nanostructured coatings exhibit insufficient reproducibility for prime reliant applications. Second, the characterization tools available for measuring coating properties are inadequate. Third, and perhaps most important, design tools for nanostructured coatings generally do not exist.

Flame Spraying process, Physical Vapour Deposition (PVD) and Laser Shock Peening are *surface treatments* that can enhance the gear performances by modifying surface hardness, surface roughness, friction coefficient and oil wettability. Today these treatments have to face with the conservative policy of the gears sector and for this reason are rarely used.

## 3. X-GEAR Technologies

X-GEAR is focused on developing a new series of gears with “eXtra powers” based on an *innovative combination of new materials, new surface treatments and manufacturing/design tools*, as well as the *development of a knowledge platform* implementing guidelines and best practices for a wider diffusion of the project results.

### 3.1. New Materials

One of the main topics of the X-GEAR project is the analysis and development of *new materials* for a new generation of gears. The research is mainly focused on three categories of materials: air-hardening steels, advanced powder steels and nanopowders.

The air-hardening steels are a new family of high performance materials that are more environmental friendly (the hardening in oil bath is no longer necessary), and also improve the manufacturing

process and lower the costs by up to 30% [3], [4]. In the worldwide scenario few steels makers are developing these materials and, up to now, any gears production has been launched at industrial level. The X-GEAR project intends to enlarge their knowledge and promote the diffusion of these materials on the market of engineered components.

A second field of research on new materials is represented by the advanced powder steels. Powder metallurgy enables the production of parts with complex geometries, as gears, at low costs.

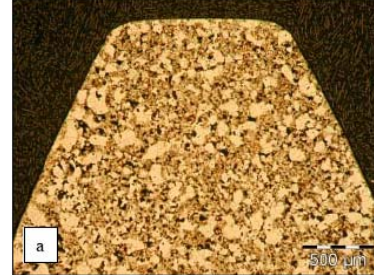


Figure 3: Microstructure of sintered gears - tooth tip region [6]

The amount of waste material is often negligible as a consequence of the minimal necessity to machine the parts and use of ecologically harmful cutting fluids is avoided. [2]. In X-GEAR two main families of sintered steels are taken into account: pre-alloyed powders, in which water

atomisation process allows alloying elements (added to the molten steel before atomisation – e.g. Fe-0.85 Mo FL4400) and sintered powders based on pure iron powder to which alloying elements of fine particle size are bonded by partial diffusion (e.g. Fe-1.5 Cr-0.2 Mo). To assess the feasibility of producing transmission gears by powder steels, a process route consisting of compaction, sintering, surface densification and heat treatment is investigated.

The third category of material analysed in X-GEAR are the nanopowders, detonational nanodiamonds also called UDDP. They have a monocrystal structure with an average particles size of 4 - 6 nm and a heat resistance up to 950°C in atmosphere. The modification of the UDDP surface allows to create wear-resistance coatings for gears, increasing the micro hardness up to 10000 kg/mm<sup>2</sup>, reducing the friction down to 68% and increasing the corrosion resistance. The X-GEAR project is also focused on the development of highly-effective industrial coating technologies with chemical and galvanic coatings with UDDP for composite materials.

### 3.2. New Surface Treatments

Several surface treatments are investigated in X-GEAR in order to enhance the gear performances by modifying surface hardness, surface roughness, friction coefficient and wettability.

Flame Spraying - High Velocity Oxy Fuel (HVOF) (Mo; WC+12%Co), Thermal Spraying Detonation (Mo; WC+12%Co), Physical Vapour Deposition PVD (TiCrC; TiCrN), Nitriding + PVD (duplex – Nitriding+TiCrC), Electron Spark Coating (TiC+Cr3C2+Ni+5%ND; TiC-TaC-X18H15+5%ND) and Chemical Method (Ni+UDDP + B; Ni+UDDP) are surface treatments that are analysed in X-GEAR project and used in combination with the abovementioned new materials, for a new generation of gear drive-trains.

In addition to these methods, X-GEAR project is focused on developing a very new technique for treating gears: the Laser Shock Peening (LSP). This treatment utilises a very high power laser beam (GW) fired at the surface to be peened for very short times (ns). This vaporises the surface (or an ablative layer) and thus generates a plasma cloudburst which generates very high shock waves in the surface being peened. The technique of laser shock peening using water as a tamping medium to improve shock load efficiency has now been developed to commercial application for enhancing the fatigue strength of titanium blades used in civil jet engines. It has been shown to work on very hard steels (58...62 HRC) where it can generate compressive stresses up to 1400 MPa and is effective to

depths of 2 mm. This combination of properties makes it ideal for enhancing the bending and contact fatigue strength of gears.

### 3.3. X-GEAR Knowledge Platform

X-GEAR aims at setting up a Manufacturing-Design Tool and a Knowledge Platform implementing guidelines and best practices developed in the project. The software makes the systematic approach developed in the project available and easy exploitable for expanding the knowledge base of the large number of SMEs operating in the mechanical transmission sector. The software tool is designed to enable: rapid query of the databases through advanced searching technologies; graphical visualisation of properties; comparison of the performance of the different materials, optimal selection for given design applications. The software is also provided of a user friendly interface for an easy interrogation of the database and the retrieval of the information. The design tool is used both to assist the User in the early stage of the gears design and to optimise their final configuration.

### 3.4. X-GEAR Pilot Applications

The high performance gears resulting from X-GEAR will be characterised by a number of advantages compared with standard gears obtained using traditional technologies and heat treatments, including an improved efficiency, due to reduced tooth-related friction losses, and increased component life, due to reduced operating temperatures under full load. Also lubrication requirements will be substantially reduced.

The range of applications for the new gears is very large and it covers small applications, such as for portable electrical devices, medium power industrial and commercial drives, such as for conveyors or cranes, as well as large gearing for the process industries or industrial drives. As the range of applications is so large the project is focusing on two sectors: automotive, and wind energy production.

The choice of the application sectors is related to the range of gears manufactured by the participating SMEs and it is also motivated by the need of demonstrating the selected technologies in sectors characterised by different production volumes as well as technical, economic, and quality constraints. The automotive sector is in fact characterised by the need of more cost-effective processes due to the large market demand while the wind energy production sector is characterised by the need to improve the performance of the turbine gearboxes in terms of reliability, noise and efficiency. The selected technologies in terms of new materials and surface treatments will be combined in a way to satisfy the above constraints. The project will focus on helical gears, being the type of gear most utilized in these sectors, which operate much more smoothly and quietly than spur gears. For this reason they are used in almost all car transmissions and gearboxes.

## 4. Conclusions

The strategic objectives of X-GEAR project include a wider diffusion of the novel technologies and new materials in order to strengthen the scientific and technological bases of the European Gears and Transmission Parts industry and encourage the international competitiveness of the European Gears and Transmission Parts Industry with respect to products manufactured outside Europe.

It is strategic for the mechanical transmission sector to reduce the environmental impact of heat treatments, in particular oil quenching, and the new developments in air hardening steels, as opposed to oil quenched, offer distinct advantages on such respect, and to reduce the manufacturing time and the number of process stages in gear manufacture, especially for small batches of high performance gears.

X-Gear will address the above strategic objectives together with the development of guidelines, best practices and manufacturing and design tools related to the novel technologies proposed with the aim of stimulating standardisation and harmonisation and facilitating of the emerging technologies to the large and scattered European community of SMEs of the mechanical sector, including gear producers and machine producers.

## 5. Acknowledgements

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