IMPROVING THE TEETH AND BEARING RACEWAY SURFACE ROUGHNESS QUALITY BY GRINDING AND SUPERFINISHING PROCESS MASTERING

De Looze, J.B.
Dynamic Systems Product Center
EUROCOPTER Company
France

OVERVIEW

As a consequence of the increase in EC Helicopters sales, the manufacturing workload, in Eurocopter Dynamics System Product Center, has ramped up from 25 to 30 % every year. At the same time, EC has increased the Dynamic Systems reliability, and consequently, now matches high quality design requirements. The annual new Gears Boxes developments have also brought more and more integrated bearing raceway on gears, using EC practiced Deep Nitriding process. Teeth and raceway require a high surface condition level. In addition, it has to be noted that gears and integrated bearing raceway are parts of core competency fields in the Dynamics System Product Center.
Therefore, ramp-up and reliability requirements impose a perfect mastering of the manufacturing process, under a high level of industrial constraints and to avoid any industrial perturbation. Matching the design surfaces condition requirements increases the risk of burns and cracks defects, so, the key of success lies in anticipating actions.

Root causes analyses revealed that the main contributors include burns detection process realized by NitWater etching, grinding process variability, limiting state surface of grinding used to mitigate health defects occurrences risks, and non-efficiency of Superfinishing process. In addition, the diversity of morphology range, of functionalities complexity and of the parts' dimensions, makes these issues particularly difficult to address. Finally, the quality department has reported a highly dispersed state in the surface measurement caused by the filtering roughness method (ISO2CR Filter).

A study carried out on the roughness filter impact has shown that the ''Gaussian'' filter is, for several reasons, the best filter on the market today and that the ISO2CR filter brings up over-shoots. Changing roughness filter therefore means developing a new roughness characterization value, based on the ''Gaussian'' filter, tested and qualified during the new gearboxes development. It has also revealed that there is no possibility to transform the roughness measurement from the ISO2CR filter to the 'Gaussian'' filter. Several technologies were identified for comparison tests: an optimization of 'Smuritropy process' used in EC work-shop, the ISF (Isotropic SuperFinishing process), the Vibro-Finishing, the Honing and the Belt grinding process. The ''optimised Smuritropy process'' was the most efficient and allows us to achieve the expected process robustness. Only some internal diameter of race way required honing process. The ''optimised Smuritropy process'' is based on a specific ceramic media, with adapted form and size.

The defined specifications for roughness robustness are completely reached, including reducing working time by a factor of 2. This results in reducing recurring costs and consumable costs as well as in respecting the environment. In addition, simulation of grinding and Smuritropy process projects are now launched to perform the mastering of finishing operation.

1 BACKROUND

As a consequence of the increase in EC Helicopters sales, the manufacturing workload, in Eurocopter Dynamics System Product Center, has ramped up from 25 to 30 % every year. Ramp-up and reliability requirements impose a perfect mastering of the manufacturing process.Teeth and raceways of the gear require a high surface condition level. So, the key of success lies in anticipating actions, to perfect superfinishing robustness process.

2 OBJECTIVES / STRATEGIES

The objectives defined to solve the requirements have included: (i) Giving robustness to super finishing process; (ii) Increasing the grinding required surface condition and making the grinding process robust; (iii) promoting a common superfinishing technology for teeth and race way features to cover the variety of the parts; (iv) minimizing the recurring cost impacts, the non-recurring cost and cycle impacts on the manufacturing ramp-up; (v) optimizing the measurement method, the choice of filters; (vi) taking into account the environmental needs; (vii) capitalizing the expertise of surface roughness requirement.

The present work first aimed to investigate the diversity obtained for the measurements of the surface finish on the gears and to propose an alternative solution, in terms of methods or surface finishing characterisation. The work then aimed to improve the current finishing process and develop simulation tools.

3 CARACTERISATION OF SURFACE FINISHING

3.1 Generality

Surface finishing is an essential stage in mechanical engineering as it raises several issues related to friction, wear, lubrication, leakage and fatigue resistance. The end roughness is directly linked to the life duration of the part.

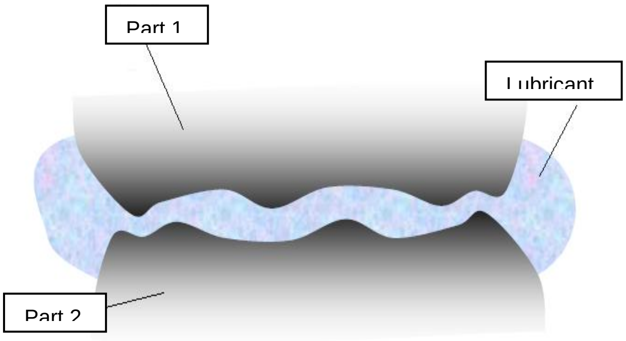


Figure 1: Two parts separated by an oil film

The surface finish is defined according to three different parameters: the form, the waving and the roughness. All parameters in our profile are noted **P** for primary, **W** for waving and **R** for roughness. **[1]**

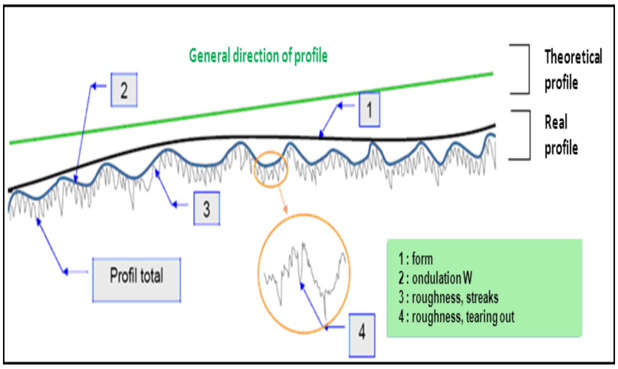


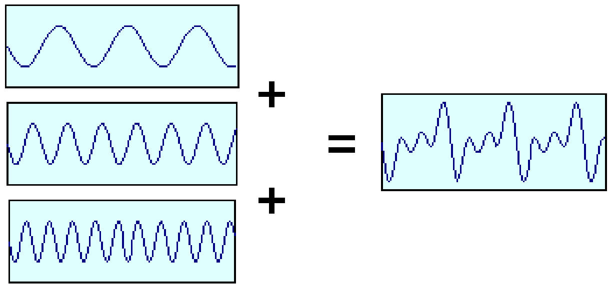
Figure 2: Representation of the profile defects

The waving and roughness analysis of a profile is carried out via an electronic filtering of the primary profile (adjusted total profile) according to the standard of the ISO 4288 average line **[2]** – standard currently used by aeronautical industries to characterise the surface finishing of the gears and of the bearing raceway (cf. **Fig. 2**).

3.1.1 Filtering Concept

The filtering of a profile is as an electronic circuit, which performs a signal processing operation.

This means that it reduces some of the signal components and allows others to pass through.
The filtering modifies some of the input signal in the time and frequency domain.
According to the theory of Fourier series, a signal can be considered as the sum of sinusoidal signals (infinite number if necessary) at different frequencies.



Then, the role of the filter is to modify amplitude and phase of the sinusoidal signals.

3.1.2 Principle of the average line method

The base length (cut-off) is equal to the profile filter wavelength, which allows the separation of the roughness and waving components (**Fig 3)**. Five base length or cut-off values are normalised: **λc** = 0,08mm, 0,25mm, 0,8mm, 2,5mm ou 8mm **[2] (Fig 4).**

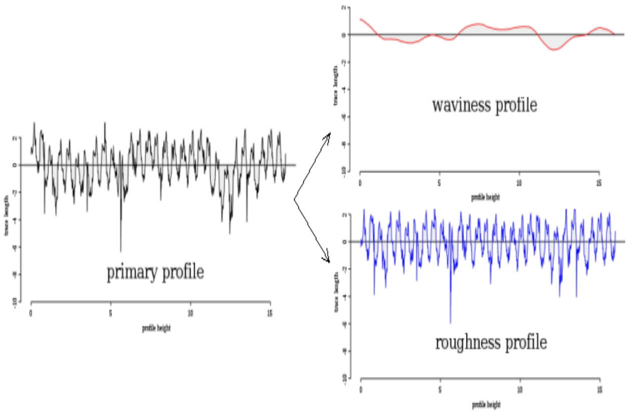


Figure 3: Separation of roughness and waving

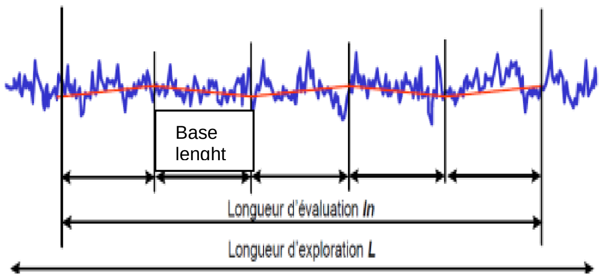


Figure 4: Representation of the average line (Red colour)

3.1.3 Parameters linked to the average line

Two roughness parameters have been used in this study:

Ra

The **Ra** is the universal roughness parameter. It is defined as the sum of the surface areas of the peaks and valleys located along the average line on a base length “l”. This parameter is easy to define and gives a general description of the variations in height. It does not however distinguish the profile peaks and valleys.

$$Ra = \frac{1}{l}\int_{0}^{l} |y(x)| dx$$

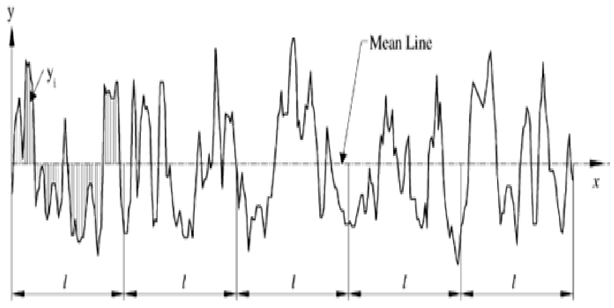


Figure 5 : Profile roughness

Bearing length rate Rmr (Tp):

The bearing rate allows characterising a surface finish profile functionally. It is the ratio of the profile bearing length at a section level **c, Ml(c)** on the evaluation length **ln**. The graphical transcription of the bearing rate is given by the Abbott Firestone curve:

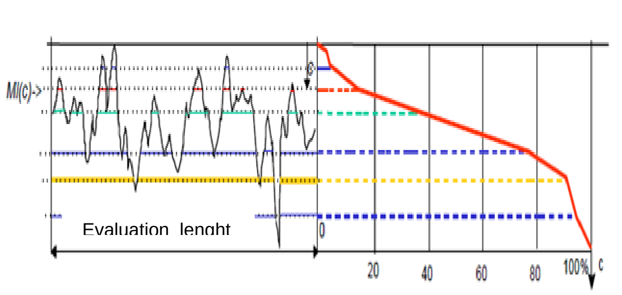
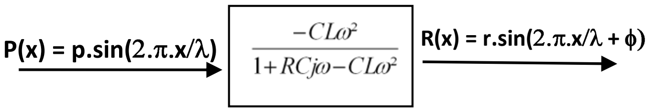


Figure 6 : Roughness profile and ABBOTT curve

3.2 Filter analysis

3.2.1 ISO 2CR filter (currently used at EC)

The ISO 2CR filter is an analog and digital filter. It reacts, as a causal system, to an input signal. **[3; 4]** The phase shifting is a distinctive feature of the causal system.



The BODE diagram in **Fig. 7** shows that the ISO 2CR filter relays 75%.

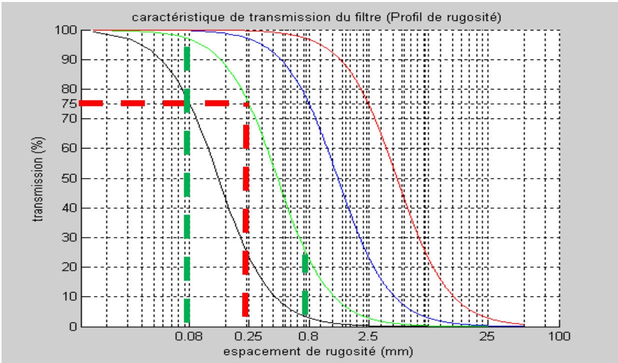


Figure 7: BODE diagram of the ISO 2CR filter Cut-off 0.25

It has to be noted that the transmission values at the cut-off frequencies around λc=0,25mm will be transmitted:

- Greater wavelength, i.e. λ=0,8mm will be transmitted at 20%
- Smaller wavelength, i.e. λ=0,08mm will be transmitted at 99%

Fig. 8 shows the behaviour of the ISO 2CR filter on the primary profile:

In blue, the primary profile (input profile) with the Sinus function (2ΠxT)/0,8 cut-off=0,8mm; in red, the roughness profile (output profile) after applying the transfer function. In order to evaluate the reaction of the ISO 2CR filters, an analogy between the temporal and spatial frequencies (**1mm = 1 second**) is proposed. The transfer function of the ISO 2CR filter is therefore represented for a probing velocity of 1mm/second.

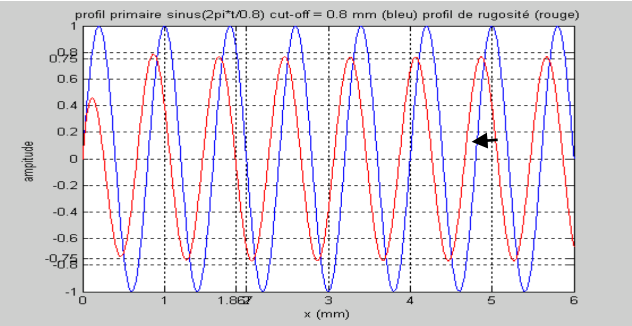


Figure 8: Reaction of the ISO 2CR filter (in red) on the primary filter (in blue)

The major problem with this filter is that it does not contain a non-linear phase that can imply important shift phases in the roughness profile. The second issue is that this filter is linked to the filter transmission of 75% to the cut-off length. In addition the sum of the roughness and waving profiles is different from the primary profile **[5].**
"The 2CR filters can be used to evaluate the parameters Ra and Rz, however, for the other parameters, the distortion is significant", extracted from the ISO 3274 1996 standard **[6].**

Capability study of the ISO 2CR filter

A study of the capability and repeatability of the bearing rate measurement is realised on a sample. The normal distribution of the ISO 2CR filter is represented on the graph below) **[7] (Fig 9**). It can be seen that the normal distribution is relatively flat, suggesting variability and non-robustness.

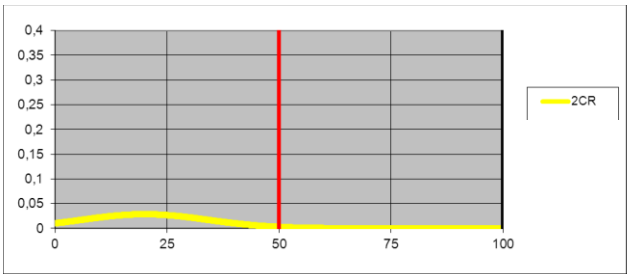
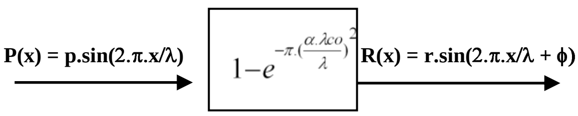


Figure 9 Capability study of the ISO 2CR filter

3.2.2 The ISO 11562 Gaussian filter

The Gaussian filter is a mathematical function which is applied to the profile data.
The roughness profile relays 50% of the primary profile, at the cut-off length. There is no shift phase, which is an important asset for the method of analysis **[8].**



The Gaussian function is dragged from point to point in the primary profile. At each position, a result point is calculated by applying the weighing formulae on the neighbour points upstream and downstream the cut-off length (Gaussian curve width). The set of these result points corresponds to the average line (cf. **Fig 10).**

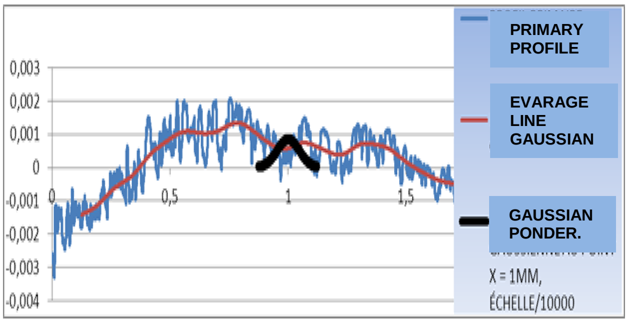


Figure 10 : Representation of a Gear Gaussian filter average line

Figure 11 represents, in blue, the primary profile (input profile) with a Sinus function (2ΠxT)/0,8 cut-off=0,8mm and in red the roughness profile (output profile) after applying the transfer function. In order to compare the Gaussian filters, an analogy between the temporal and spatial frequencies (**1mm = 1 second**) is proposed. The transfer function of the Gaussian filter is therefore represented for a probing velocity of 1mm/second.

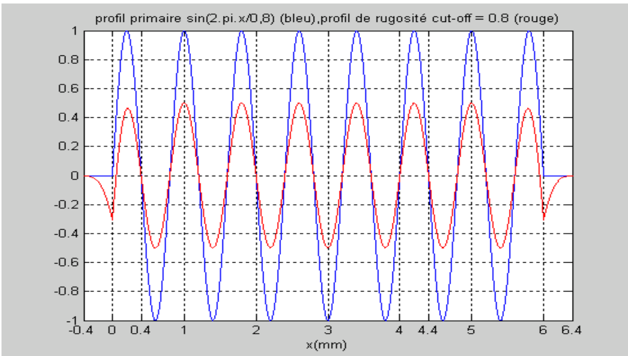


Figure 11: Reaction of the Gaussian filter (in red) on the primary profile (in blue)

The BODE diagram in **Fig. 11 & 12,** shows that the Gaussian filter relays 50% at the cut-off frequency (green curve).

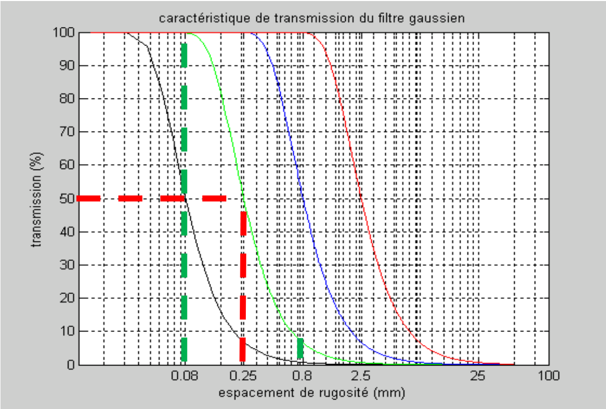


Figure 12: BODE diagram of the Gaussian filter

The transmission values at the cut-off frequencies around λc=0,25mm will be transmitted:

- Greater wavelength, i.e. λ=0,8mm will be transmitted at 7%
- Smaller wavelength, i.e. λ=0,08mm will be transmitted at 99%

Capability study of the Gaussian filter

A capability and repeatability study on the bearing rate measurement has been carried out (20 measurements). **Fig. 13** represents the Gaussian filter normal distribution. On the contrary with the ISO2CR, the Gaussian filter reveals a high peak, suggesting a high capability and robustness.

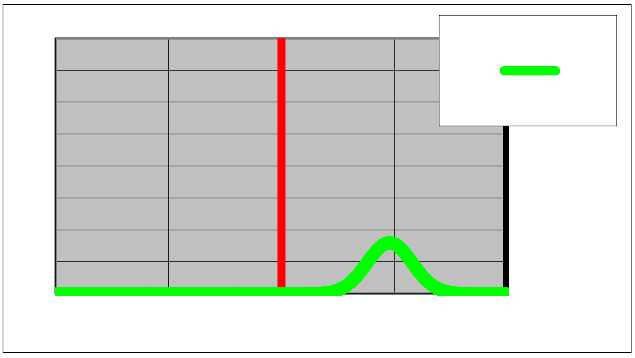


Figure 13: Representation of the Gaussian filter normal distribution

Following the result obtained on the Cp and Cpk indicators, the measurement process with the Gaussian filter is centred halfway to the lower bearing rate limit and the specification limit. This is a reliable process as it is capable and centred **[9].**

3.3 Comparing the ISO 2CR filter and the Gaussian filter

The Gaussian filter is more centred on the cut-off frequency than the ISO 2CR filter.

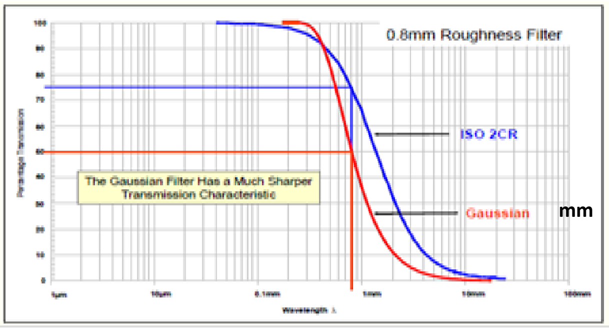


Figure 14: Comparing the BODE diagrams of the ISO 2CR and Gaussian filters

3.4 Effect of the filter on the surface measurement

This study mainly deals with the ISO2CR filter (existing) and the Gaussian filter (target).

3.4.1 Effect of the ISO 2CR filter

3.4.1.1 Measurement of the scratched standard

In order to highlight the overshoot phenomenon generated by the ISO 2CR phase shift, measurements on a scratched standard (scratch depth of 8,6 μm) allow to identify the excess resulting from the filters (see **Fig 15**).

This stage also aims to identify the defects that may generate one or several overshoots after filtering:

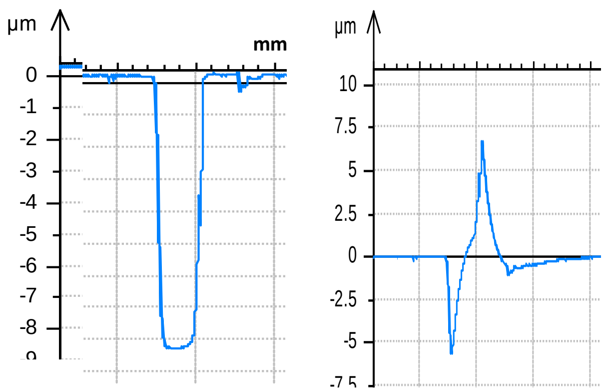


Figure 15: Raw profile on the left and filtered ISO 2CR profile on the right

The filtered profile with the ISO 2CR filter completely changes the raw profile by creating an overshoot which generates a virtual peak that does not exist on the profile. The method of the bearing rate calculation takes into account the maximal height of the peak; the distortions resulting from the filter highly affect this parameter.

This type of defect is specific to a standard. The overshoot phenomenon is random and cannot be mastered. In order to evaluate the behaviour of the ISO 2CR filter, measurements on the gear families have been carried out.

3.4.1.2 Specimen test measurement

The measurements have been carried out on Specimen Test, carburized, with two different surface finishing qualities.

The Specimens with the first surface finishing are named Specimen Test N°1 (ST1).

Note: Quantity 6, 2 measurements for each specimen.

The Specimens with the second surface finishing are named Specimen Test N°2 (ST2).

Note: Quantity 6, 1 measurement for each specimen.

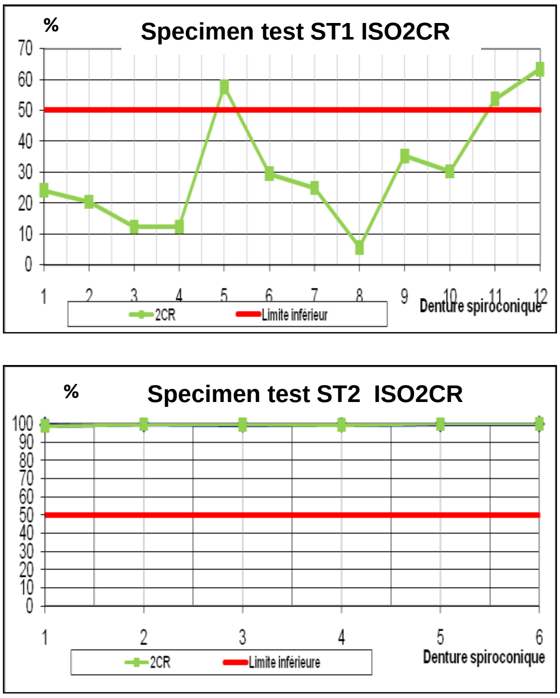
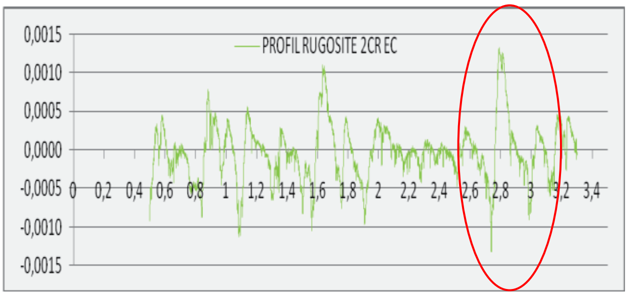


Figure 16: Evolution of the bearing rate with the ISO 2CR filter for ST N1 & ST2

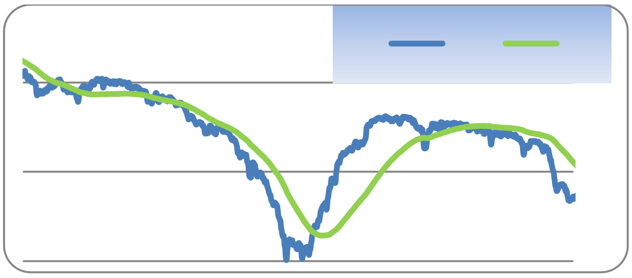
Fig.16 shows the measurements carried out with the ISO2CR filter.

The ST2 measurements are similar; on the contrary, the ST2 results are very dispersed.

To better understand the non-compliance rate obtained with ST n°1, the roughness profile of the ISO 2CR on the part n°8 is given below (case for which the bearing rate is minimum):



The circled peak represents the overshoot phenomenon, which is directly linked to the shift phase of the weighing function average line of the ISO 2CR filter. Below, the behaviour of the filter average line on the primary filter in the circled zone:



The ISO 2CR average line filter (in green) is shifted compared to the valleys. This shift leads to a different process on the roughness profile. The local defect (valley) will be represented by a reduced valley and an amplified peak (overshoot phenomenon), hence a result which does not comply with the bearing rate at a cut-off of 0.8 µm for the highest peak.

Below, a representation of the ABOTT curves to exemplify the bearing curve of the roughness profiles.

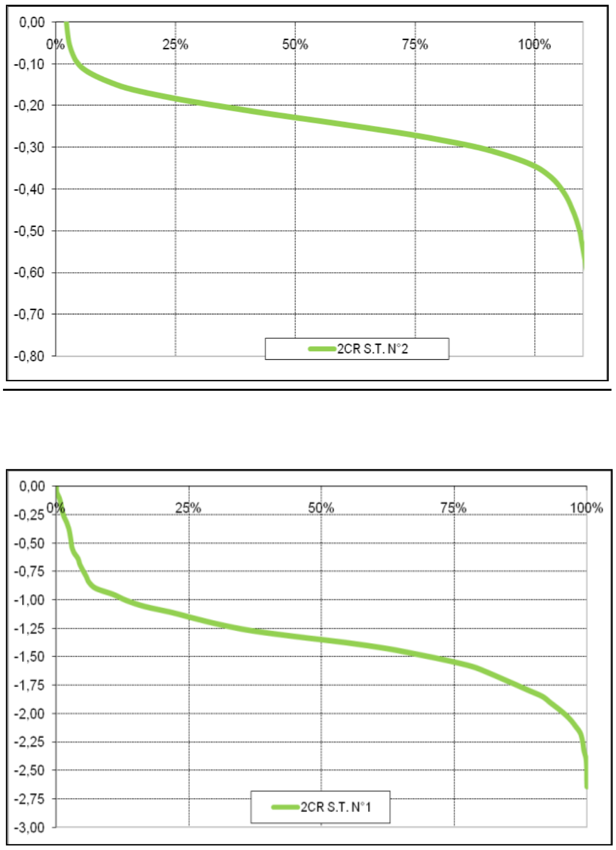


Figure 17: Abbot curve between ST1 et ST2

Fig 17 representThe ISO 2CR. S.T. N°1 roughness profile has a cut-off of -1.4µm at 50% whereas the ISO 2CR S.T. N°2 profile has a cut-off of -0.23 µm at 50%, i.e. 6 times less than the ISO 2CR S.T. N°1 filter values. **[9]**

In conclusion, the overshoot phenomenon augments the roughness profile in such a way that it does not comply with an acceptable surface finishing (ST1). On the contrary, the shift phase will not have any overshoot effect on a perfect primary profile (ST2).

3.4.2 Influence of the Gaussian filter

3.4.2.1 Measurement on a scratched standard

In order to highlight the reaction generated by the Gaussian filter, measurements on the same scratched standard than for ISO2CR (scratch depth of 8,6 µm) have been carried out. **Fig. 18** shows the standard measured with the Gaussian filter**:**

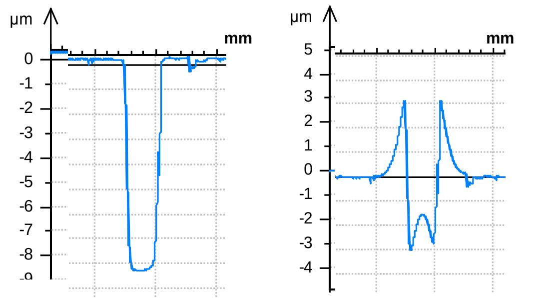


Figure18: Raw profile on the left and filtered profile Gaussian on the right

The filter generates a profile which is similar to reality but with a repositioning of the average line. The peak-valley distances are slightly different, 6.16µm instead of 8.6µm on the raw profile.

3.4.2.2 Comparing the Gaussian filter with ISO2CR

Fig. 19 shows the ST1 & ST2 specimen test measurement obtained by the Gaussian and ISO2CR filter.

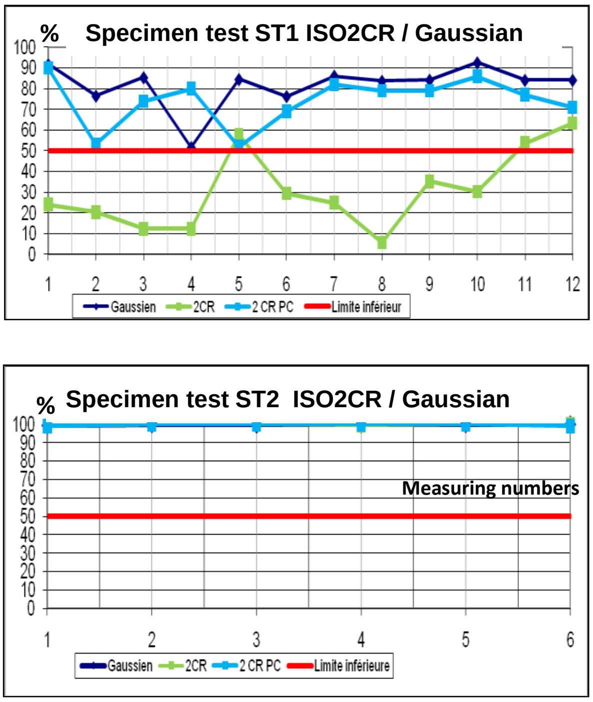


Figure 19: Evolution of the bearing rate with ISO 2CR and Gaussian filters, ST1 & ST2

Regarding the specimen test ST1 and measured with the Gaussian filters (cf. **Fig. 18**), all parts comply with the top quarter, whereas the parts measured with the ISO 2CR filter are located in the bottom half of the graph.

Regarding the specimen test ST2 and measured with the Gaussian and ISO 2CR filters, all results are on the top compliant.
To better understand the difference between the two filters, the roughness profiles of the ISO 2CR S.T. n°1 and Gaussian S.T. n°1 filters on the part n°8, are presented (case for which the bearing rate is minimum).

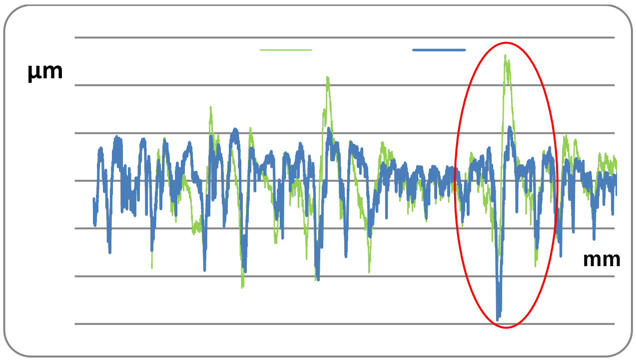


Figure 20: Roughness profile from the ISO 2CR and Gaussian filters

The circled peak represents the overshoot directly linked to the shift phase of the weighing function average line of the ISO 2CR filter. The Gaussian filter gives a valley of a 1.5 µm depth. **Fig. 21** shows the behaviour of the filters average lines on the primary filter in the circled zone.

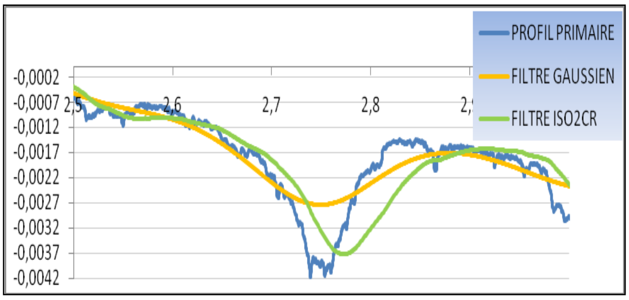


Figure 21: Primary profile + average lines of the ISO 2CR and Gaussian filters

The position of the Gaussian filter average line is centred on the primary profile, raising the value of the optimal roughness profile. The ISO 2CR filter average line is shifted compared to the primary profile, which gives an incorrect result compared to the norm. A representation of the ABBOTT curves exemplifying the roughness profile bearing curve is given in **Fig. 22.**

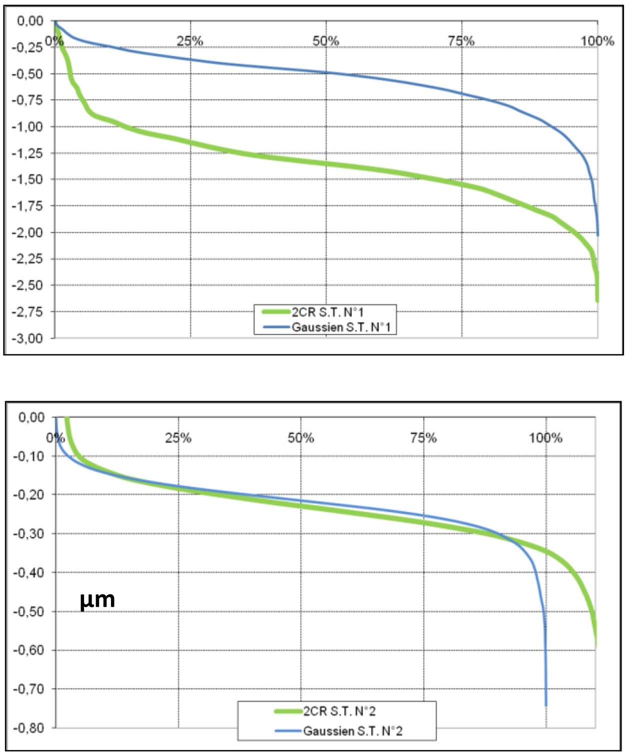


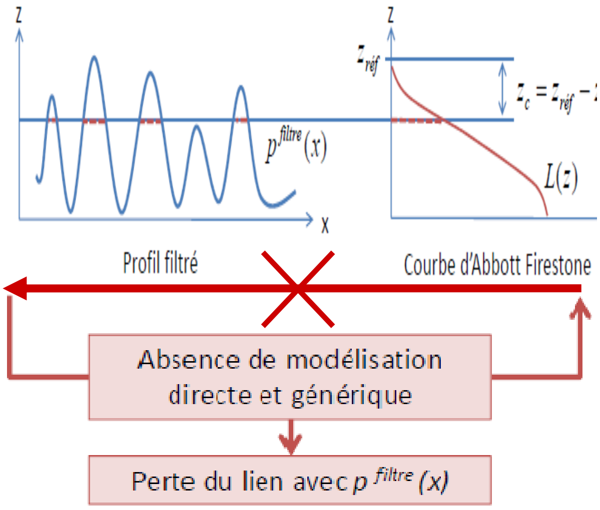
Figure 22: ABBOTT curve of ST1 ST2 with filter ISO 2CR and Gaussian

The ISO 2CR ST1 roughness profile from the ABBOTT curve has a cut-off of -1.4µm at 50% whereas the Gaussian ST1 profile has a cut-off of -0.50 µm at 50%, i.e. 3 times less than the ISO 2CR filter values.
On the contrary, the ISO 2CR ST2 roughness profile from the ABBOTT curve has the same value than the Gaussian filter.

In addition, in order to complete the study, a gear teeth and race way surface roughness data base was created, for each family gear, depending on the material, using several roughness filters and another surface criteria characterization, in accordance with features requirements.

3.5.3 Analytical relationship between the roughness criteria of the ISO 2CR and Gaussian filters

The bearing rate corresponds to the ABBOTT curve, which represents the ratio between the roughness profile bearing length at a given level zc (according to a reference zref) and its total bearing length.



When using an ABBOTT curve, some information may be lost (modified by the filtering) which does not allow a generic modelling of the Tp estimator from the Gaussian and the ISO 2CR filtering.
A set of experiments can be carried out to determine the practical relations that would gather the Tp values obtained with a Gaussian and RC filter. It is however impossible to ensure such relationships. The phase shift with the ISO 2CR and Gaussian filters makes the setting of an analytical or empirical bridge random. Each roughness profile comes from a primary profile, which directly depends on the machining procedures **[10].**

Changing the roughness filter therefore means developing a new roughness characterization value, based on the Gaussian filter, tested and qualified during the new gear boxes development. In a second time, a new surface roughness characterization criteria will be proposed, which will bring a complementary characterization of the gears teeth roughness.

4 PROCESS IMPROVEMENT

The second part of the project has consisted in identifying the technologies capable of ensuring a perfect mastering of the high quality finishing process. To do so, an optimizing test plan has been set up. These tests aimed to assess the process capability:

- Consolidating, in manufacturing, the quality of roughness criteria (as set by the design specification) on the internal roller raceways and external roller and ball bearing raceways with or without collar, and on the active flank of the gear teeth.
- Unimpacting on the shape and the circulars waving criteria of the different raceways.

4.1 Technologies Comparisons

Different technologies have been compared: an optimisation of the Smuritropy process and the Honing.

4.1.1 New Media Evaluation

Surface finishing is currently obtained by a superfinition process: the Smuritropy.

The functioning principle is as follows: the gears are fitted on a rotating spindle. They are immersed into a circular tank filled with abrasive media. In addition, the gears turn around the vertical axis of the tank. (cf **Fig 23**). During the abrasion cycle, the media is watered with water and additive liquid (e.g . soap, antioxidant). At the part/media contact level, the exerted pressure, associated with the media relative flux, creates an abrasion which improves surface finishing.

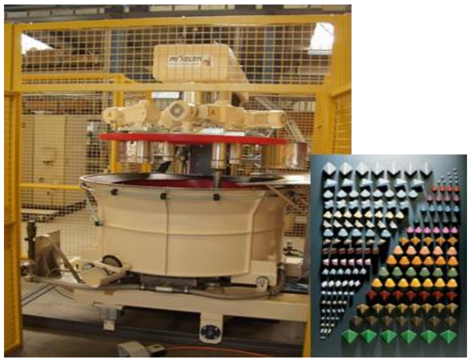


Figure 23: Smuritropy Machine / Media

In order to augment the abrasion effectiveness, the media densities as well as its 'superfinishing' capacity have been augmented. The first tests allowed selecting the media composition, dimensions and shapes as required for our study. (cf. **Fig. 24 & 25).**

The tests have been carried out on spiral bevel gears and spur gears with integrated raceways.

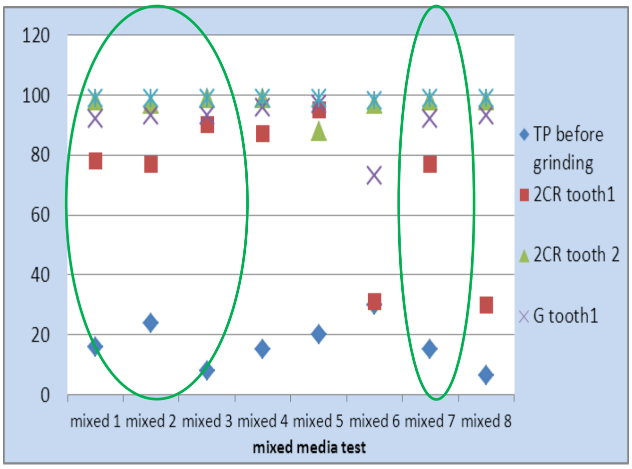


Figure 24: Comparison of different mixed media on MGB Spiral bevel Pinion

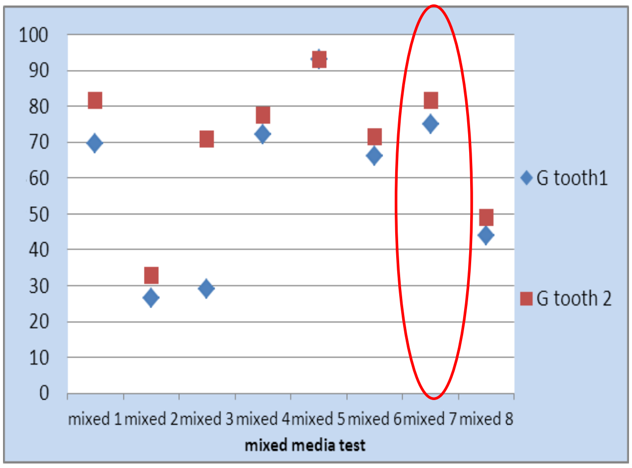


Figure 25: Comparison of different mixed media on MGB Spiral, & Spur Gear

The best compromise between the spur and spiral bevel gear teeth is the « mixed n°7 ».

The Mixed media n°7 is then tested on a set of gear families. The graph on **Fig. 26** shows that the Gaussian filter measurement is on the top quarter. (Except for the two antepenultimate cases for which superfinishing time was weak).

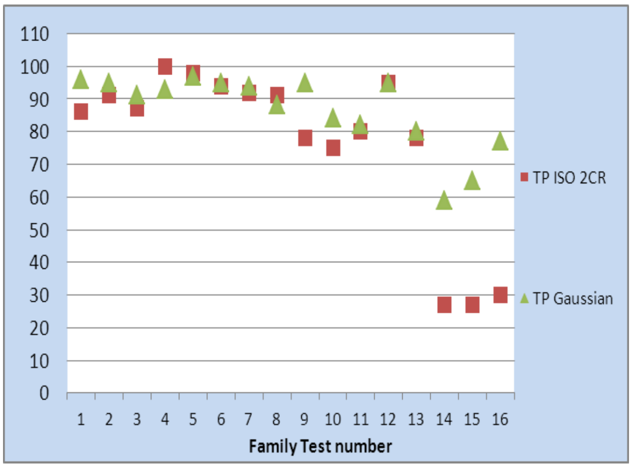


Figure 26: Evaluation of ‘Mixed Media 7’ on MGB Gear range

The obtained roughness on the raceways is Ra 0.05µ for the roller raceways and Ra 0.07 for the ball bearing.

The new media mixed fully meets the roughness requirements.

4.1.3 Honing Process Evaluation

In addition, we have assessed the honing process which enables to reach the quality, shape and surface requirements of the bearing raceways.
The issue is to use superfinishing with abrasive stone or grinding belt machines on complex gears, which have different shapes and sizes.

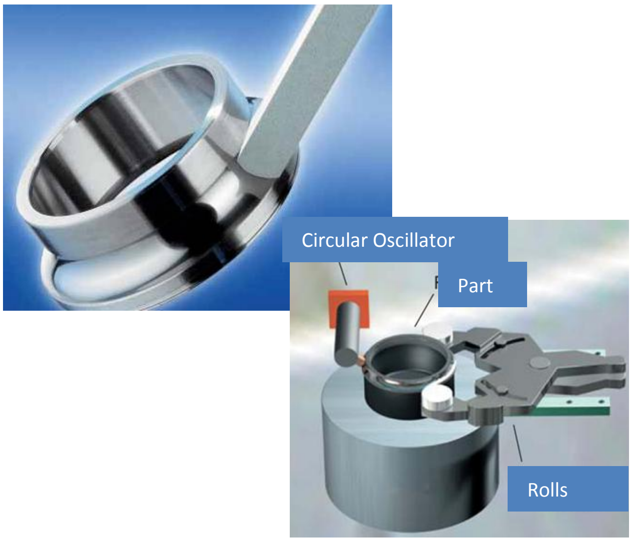


Figure 27: Race Way Honing Process

The tests on the parts have shown that:

- First, the internal and external roller raceways are easily super finished. The reached roughness (Ra 0,04 µ) is clearly superior to the demanded criteria.

Figure 28: Honing Process on a Gear Raceway

Note that the centring of the part is realised by 2 rollers. To ensure a high quality centring, these elements must rely on a precise reference of the part (e.g. teeth pitch diameter, external way; cf **Fig 28).**

- Secondly, the ball raceways are harder to superfinish. Besides a significant and stable improvement of the roughness (Ra 0,04µ), it is difficult to master the profile shape. After honing, the circular section extremities have a subsidence of few microns (about 3µm on the tested parts).
This is due to the increased honing contact pressure during the output side. The risk of non-compliance is quite high.

Remarks about the process:

- The changeover does not last more than one hour and includes changing the stone clamping, adjusting the centring and position keeping and honing.

- In general, two cycles are necessary: Rough cycle (high pressure, quick beat, low rotation and vibration), finishing cycle (low pressure, low beat, quick rotation and vibration). For our tests, the same hone was used, but sometimes with two different grains.

- The material removed by honing was around 2µm on the radius.

- The numerical control machine allows varying the feedrate along the cylinder generatrix of the raceway. This allows impacting the shape (bumped, concave, inclination).

The process can be used at a high level performance (quality, cycle time). The flexibility of the testing machine and the digital control system are important advantages for our needs (e.g. parts diversity, parameters mastering), ball raceway excluded.

Choosing and refining honing conditions (e.g. tools, speeds) necessitates some know-how. In addition, this process is very sensitive to the variations of each part (dimensional, roughness, material).

Three years were necessary to master this technology. In addition the specific attribute of our gears requires honing process adaptation for each part as well as modifications of the manufacturing operation mode in order to ensure the positioning of the part (e.g. referential).

In synthesis, the risks to master the technology on complex gear and the industrial costs are too high.
Only the honing process is kept for the through internal raceways.

4.1.4 Synthesis of technologies evaluation

To conclude, the new mixed media developed with the Smuritropy process has been selected. It will be associated to the honing process for the internal raceways. The set allows obtaining the roughness and surface finishing quality consolidated robustness.

4.2 Serial Manufacturing Implementation

The new media mix has been integrated in the manufacturing at the beginning of 2012. The new process qualification program report is not described in this document.

Evenly, this process has required a specific development in order to avoid impact on the etching inspection and conformity of the gears.

To take into account the environmental needs, a power station of filtration in closed circuit allows to treat the waste and to avoid consequent wasting water.

4.2.1 New Media Implementation

The performances obtained in serial manufacturing are superior to those obtained during the tests. The inner form of the tank (ring shape) would increase the pressure of the media on the parts.

During the 1st semester of 2012, 305 batches, 130 gear teeth and 180 raceways were controlled.

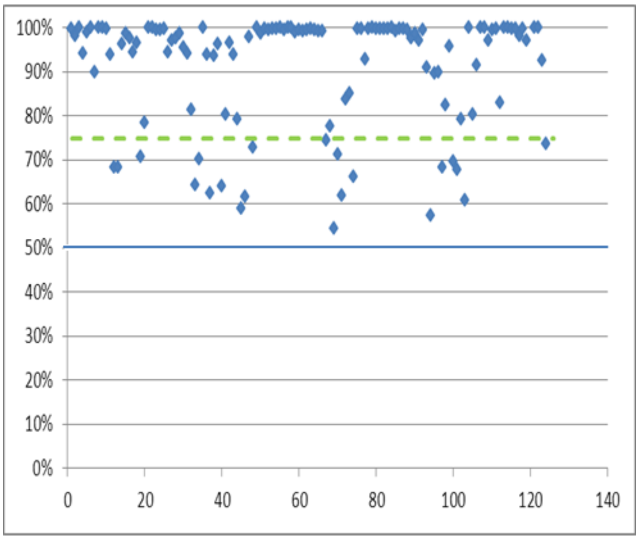


Figure 29: Teeth Roughness result with New Process

Fig. 29 shows that 82% of the results are in the top quarter and 100% in the upper half.

Fig. 30 shows that more than 85% of the roughness on raceways is in the top quarter, and 99,5 % are robust.

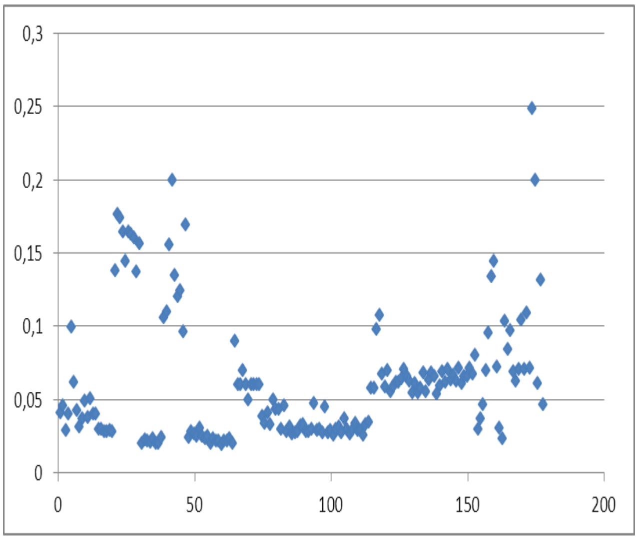


Figure 30: Raceway Roughness result with New Process

Results are very satisfactory. The Superfinishing process robustness allows increasing the race way and gear teeth surface roughness in grinding process, decreasing burns and cracks risks. In addition, new grinding wheel and specific parameters give the right robustness for bearing race way grinding process. Evenly, a thesis is running on the burns and cracks phenomena apparition understanding.

Regarding the results, all Smuritropy working time has been divided by two.

Evenly, the target is to verify that the design requirements are well respected, as dimensional and geometric, surface aspect, right tooth profile. Particularly, the non-destructive test ' NITWATER' has been checked, to guaranty that changing the media did not impact the surface preparation prior to this test.

Tooth profile Impact evaluation

To ensure that there is no impact on the tooth profile, some tests were carried out in serial conditions, but increased by a coefficient of ten.
The results show a slight degradation of 4 µ (cf. **Fig 31)**.

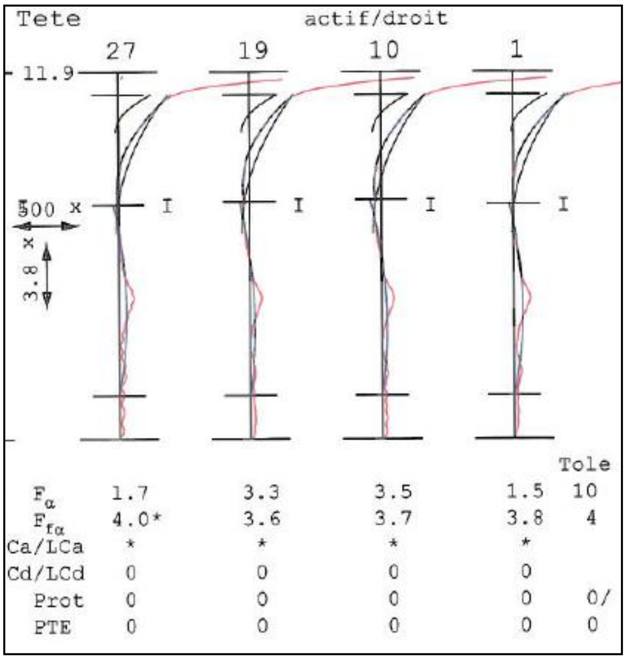


Figure 31: Teeth defect result with Cycle x 10

The 4 µ defect is located on the middle of the profile, on the right side.

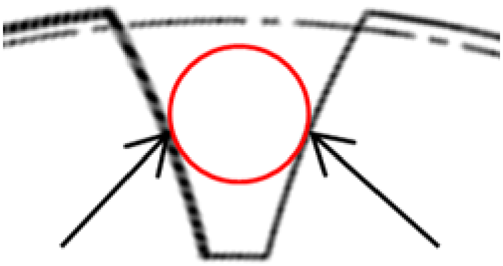


Figure 32: Teeth defect result of Cycle x 10

This study shows that in the case of a particular gear, In fact, the contact pressure between the tooth and the média. (cf. **Fig 32**). A local wear appear after a Smuritropy consequent work time (factor 10).

The follow-up of more than fifty manufacturing batches, including different gear families, in serial conditions, has never shown local defect.

Material removing Impact evaluation

A similar study has been carried out to ensure that there is no impact on the raceway diameter value. Some tests were produced in serial conditions, also increased by a coefficient of ten.

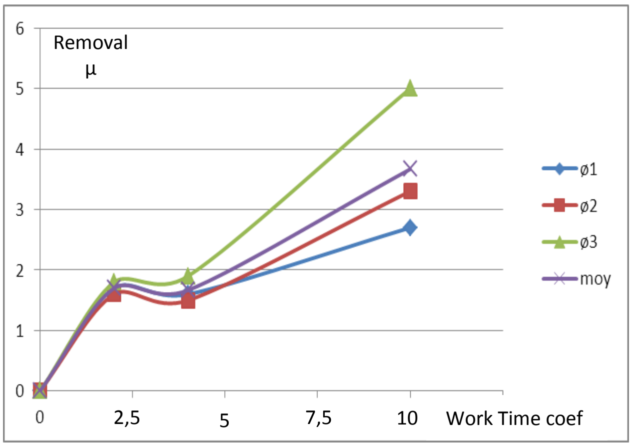


Figure 33: Removal result on raceway / work time coefficient.

The results in **Fig. 33** show a slight degradation of 5 µ of diameter dimension for a work time increased by ten. The measurement values are similar concerning the '2 and 4 coefficient '. This could be due to the dispersion of temperature measurement. The follow-up of manufacturing batch, including different gear families, in serial conditions, has never shown any impact on dimension.

4.2.2 Impact on NITWATER

A qualification plan has been realised in first half of 2012, to evaluate the impact of new process on the surface preparation prior to the NITWATER.

Effectively, the teeth and raceway roughness has substantially improved, changing the process (cf. **Fig 34).**

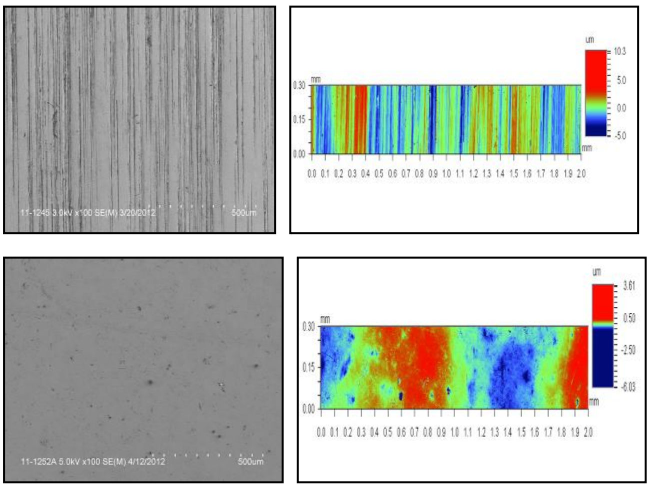


Figure 34: 2D & 3D roughness on sample before and after changing process

The follow-up of more than 150 serial manufacturing batches (1160 parts) shows that the surface preparation was not impacted by the new roughness.

5 CONCLUSIONS

The defined specifications for roughness robustness are completely reached, including reducing working time by a factor of 2. This results in reducing **the recurring costs, consumable costs and in respecting the environment.**

Changing the roughness filter therefore means developing a new roughness characterization value, based on the ''Gaussian'' filter, tested and qualified during the new gear boxes development.

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