Gearbox noise emission in stationary conditions and Production Quality Assurance

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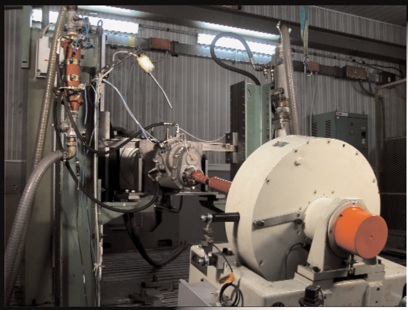
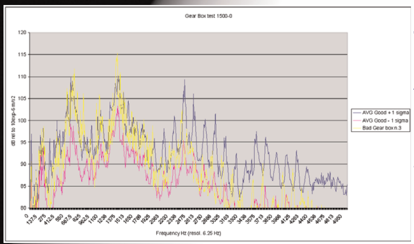
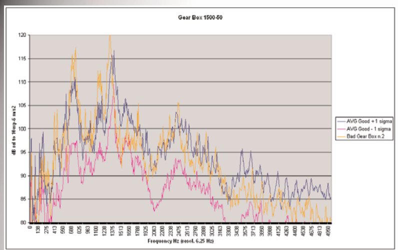
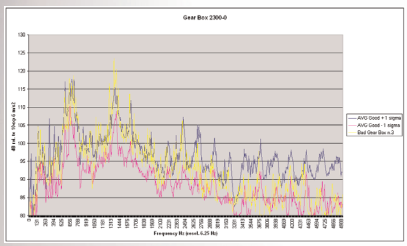
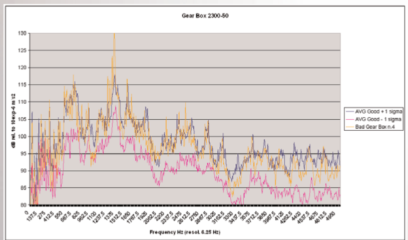










GEAR BOX TESTING ON STATIONARY CONDITIONS OF ROTATION AND LOAD

A series of preliminary test on Gear Box Test Bench have been performed in order to understand the possibility to design an automatic system for Gear Box Quality Control.
The general idea was to use vibration measurements to detect faults in gear boxes instead of noise measurements since vibration measurements is less sensitive to environmental noise in the workshop.

GENERAL INTRODUCTION

In theory any vibration and noise phenomena can be correlated under certain circumstances, i.e. whether the mechanical vibration is the "origin" of the noise, in terms of absolute values it is necessary to consider the acoustic power (Lw) emitted by the machinery, make a correlation between the Lw and the Vibration level Lv and than recalculating the estimated Sound Pressure Level Lp at a certain distance.

The Lw of the source can be determined using ISO 374x standard by using Lp measurements around the source or (more appropriate in the gear boxes case) Sound Intensity measurements according to ISO 9614/1/2. In both cases it is possible to determine the Lw of the source in 1/1 or 1/3 octaves and as dBA, dBLin values. Those Lw values are usable to certified the "product" in terms of noise emission.

From a sufficient number of Lw determination and Vibration measurements it should be possible to achieve a good confidence in correlation between them and to the estimated Lp at a certain distance.

MEASUREMENTS

Vibration measurements and Fourier Analysis of the signal where the investigation tools. An accelerometer has been positioned on the gear boxes (same position for all measurements) and the resulting signal it has been acquired and analyzed with 2 different systems. One of the system was the a multipurpose PC based analysis system for Noise and Vibration, used in this case to analyze data in Real Time and produce FFT spectra, stored on the PC Hard Disk. The other system was a much more sophisticated for analyzing data, used as a secondary system to get more information, whether necessary or not, to achieve the criterion in distinguish between "Good" and "Bad".

Frequency components in Hz

		rotation components													
		1	2	3	4	5	6	7	8	9	18	27	36	45	54
rotation	load									tooth-mesh components					
rpm	%									1	2	3	4	5	6
1500	0	25	50	75	100	125	150	175	200	225	450	675	900	1125	1350
1500	50	25	50	75	100	125	150	175	200	225	450	675	900	1125	1350
2300	0	38,3	76,7	115	153	192	230	268	307	345	690	1035	1380	1725	2070
2300	50	38,3	76,7	115	153	192	230	268	307	345	690	1035	1380	1725	2070
3000	0	50	100	150	200	250	300	350	400	450	900	1350	1800	2250	2700
3000	50	50	100	150	200	250	300	350	400	450	900	1350	1800	2250	2700
3000	16	50	100	150	200	250	300	350	400	450	900	1350	1800	2250	2700

The measurements have been performed to some "Good" and "Bad" gear boxes, judged by customer experience and usual means, from a set of measurements of "Good" ones it has been calculated the statistical average and the standard deviation in order to show some differences in the vibration energy contents.

The gear boxes under test were taken from normal production with the following characteristics:
pignon 9 teeth
crown 35 teeth
differential 10 to 19
they have been tested in the conditions reported on the table “Frequency components in Hz”.

Some graphics will explain the vibration characteristics at different rpm and load, respectively for gearbox judged as “good” and as “bad”.
It can be seen from the graphics at side the yellow curves (in all graphs) is the Gearbox classified as Bad n.3 and that the vibration level exceed the + 1 sigma reference in the 3rd and 6th harmonic of gear box tooth-meshing frequency, while the 5th harmonic it shows up only sometimes in the spectrum.

It is interesting to note that the load applied change the vibration spectrum and a lot of energy in fractional harmonics disappear, i.e. rotation is actually more stable and measurments more repeatable, meaning that test conditions shall be as “loaded”.

The fault identification was not the goal of this preliminary investigation but it could be interesting to understand that the energy within the 3rd harmonic of the tooth-meshing component is normally indicating a bad contact while energy at higher harmonics is more related to the teeth generation quality, i.e. the Glyson machinery conditions.

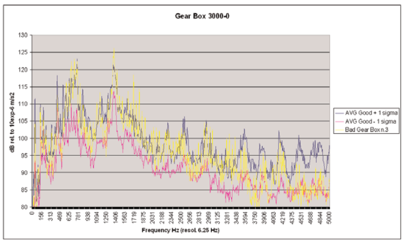
In the load conditions of 1500-50 it can be seen that there is a more stable rotation condition due to the load applied, the difference in peaks frequency components (not the level but the frequency value) is almost insignificant.

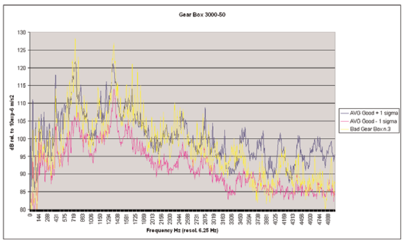
In the 2300-50 test conditions some side-bands rise up in the spectrum; side bands are usually positioned around tooth-meshing frequency with delta-F corresponding to rotation frequency.

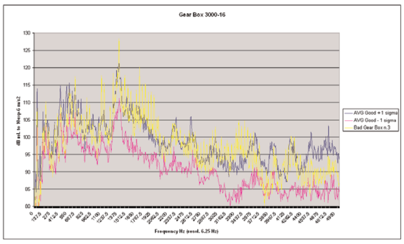
At the 3000 RPM with 0, 50 and 16 load conditions there are a lot of side-bands activities, indicating bad gear conditions, probably as a distributed fault.

Side bands activities become more visible in the 3000-50 load conditions and in the overdrive test conditions (3000-16).

To test the algorithm we estimated the average spectrum an the std-dev of a measurements set referred to gearbox judged as “good”, all in a given RPM and load conditions.



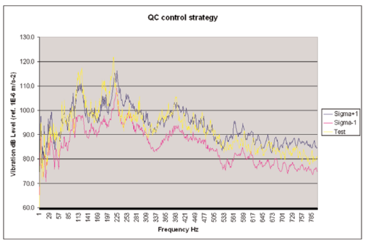




Several test have been conducted with satisfactory results, QC mask, as reference spectra, are plotted on graph below overlayed with a test sample, resulting as "bad".

Considerations

The detection of quality level and Quality assurance in Gear Boxes production can be rather easily achieved using vibration analysis comparison between Good and Bad products.
The "window" of acceptability (Reference mask) can be optimized and narrowed, once more data become available from a consistent set of measurements on several Gear Boxes, directly from production line.



From frequency analysis of the vibration signal it is also possible to detect faults typology and look directly to the source in order to correct the problem.

Combining vibration analysis results with noise and vibration measurements performed in a vehicle on the road, one can understand the real noise contribution of the Gear Box to the overall level in the car, so it is possible to study the Gear Box structure and the elements manufacturing to achieve a better result.

Among all advantages of implementing such kind of system for the Production total quality control there is also the real possibility of improving the general quality to meet car manufacturers expectations.

Advanced analysis for diagnostic and QC control

It is sometimes complicated to recognised defects from the vibration spectra generated by gearbox like devices, additionally, the QC procedure shall be applied on spectra with reasonable high resolution, greater than 5000 FFT lines, requiring a longer calculation time.

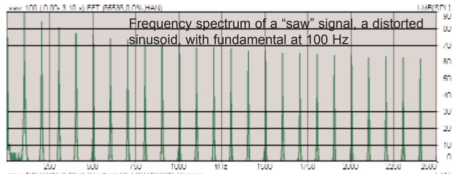
By considering the gearbox vibration phenomena as a periodic signal modulated in frequency, as a first instance, we can focused analysis on the periodicity contents: harmonics and sidebands typically, in other word all components related to rotation and to gearmesh.
Some specific signal analysis can be used to look for periodicity: autocorrelation and cepstrum for instance, the latter is more powerfull.

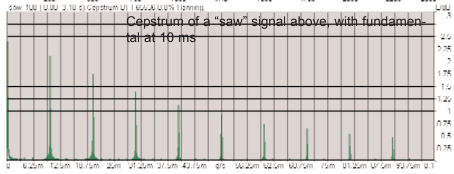
In order to simply describe the cepstrum (a kind of reverse spectrum) we can consider a sort of theoretical modulated signal, like a distorted sinusoid, showing the fundamentale and n harmonics spaced by a frequency interval equal to the fundamental frequency (see picture).

The cepstrum function simply take the spectrum as a time signal scaled as logharitmic and applies an FFT function obtaining a new function (cepstrum, see picture) in which a "time" line indicated the existance of a family of harmonically related components in the original freqeuncy spectrum.

Applying the Cepstrum function mean to transform (Fourier) from Frequency domain to time domain, the units of Cepstrum are than time and a specific dB value, not related to the energy content of the original signal but to the "number" of harmonics present (modulation level for instance). The more the original signal is distorted, or modulated, the higher will be the Cepstrum lines.

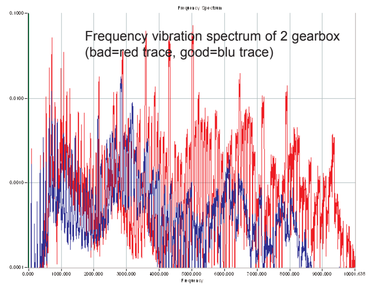
In the example, the frequency spectrum has a periodicity of about 100 Hz: the fundamental value and the frequency space between harmonic components, the Cepstrum shows a "Fundamental" of 10 ms and a family of rahmonics spaced by the same amount.

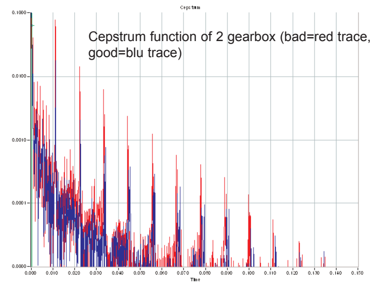




So, what can we do with the Cepstrum on gearbox QC control? It is possible to detect and evaluate a "periodicity" by looking just to a single Ceptrum line! Let's take a real world example now.

Two gearbox have been taken from the production, one as good and one as bad, Frequency spectra and corresponding Cepstra functin have been calculated and compared in the figures below.





As it is easily noticed, the level of the first Cepstra component, corresponding to the main periodicity in the vibartion spectra, have a different level, indicating a higher harmonics content in the spectrum of the "bad" gearbox.

Quality control and assurance of gearboc production might so be performed by traditional Frequency analysis, advanced analysis (Cepstrum) or time-frequency function for transient defects detection.

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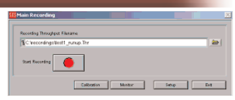
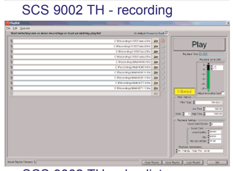
SCS 9002 QC system includes several analysis functions for detecting periodicity in rotating machines and check for defects or performs diagnostic tasks. The diagnostic software SCS 9002 TH (Time history processing) it is the tools to investigate the noise and vibration problem and design the necessary QC algorithms.
A rather unique feature of the Time History Processing, among similar products, is the capabilities to edit, playback and filter the audio signal in order to take in account the operator subjective judgement in the process of the QC strategy definition.


SCS 9002 TH - recording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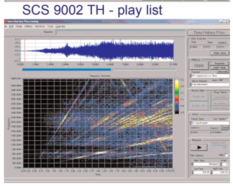
SCS 9002 TH - analysis