

## EXPERIMENTAL DETECTION OF THE FAULTS IN A GEARBOX

Ekrekli, A. \*, Güçlü, R. \* and Tahralı, N. \*

\* Yıldız Teknik Üniversitesi, Makina Fakültesi, Beşiktaş İstanbul.

### ABSTRACT

Dynamic analysis of gearboxes especially driven at high speeds has always been an area of interest for researchers. It is important to know the dynamic behaviour of a gearbox to operate it more efficiently from the friction and vibration point of views. This is important for the automotive industry. To evaluate the vibration of gearboxes produced by a military factory based in Tuzla, an accelerometer is used together with an amplifier and an A/D converter fitted in the computer. Nonrecursive digital filtering programmed by the authors manifested the contribution of vibration from each part of the gearbox.

### 1. INTRODUCTION

Dynamic behaviour of a pair of meeting teeth has been studied extensively [1,2,3]. It has always been easier to do the theoretical work for the fact that setting a transducer on the tooth at the time of running has always been unfeasible. However some researchers such as Umezawa et al obtained practical data by fixing one end of the shaft and apply shock torques to the other end. It is assumed that similar dynamic behaviour would be obtained if it was possible to do the measurement at the time of running.

Umezawa has also shown that there is a strong correlation between vibrations produced by the gears and the gear-case. A transfer function has also been formed to convert from the gear-case vibration to the gear.

It is known that fault detection is very important for gearbox manufacturers. This is usually done by instruments doing vibration analysis. These devices usually do not have access to change the parameters of the measuring unit. To have a flexible lab-based open system, an experimental measuring unit has been set up at the "K.K.K. 1013. Ordu Donatım Ana Jip Tamir Fabrikası (Jeep Factory)". The purpose of this system is to detect faulty parts in the gearboxes produced by the factory [4].

Vibration analysis is done using a nonrecursive digital filter [5]. A software is written to be used by the factory personnel. Table 1 consisting of frequency ranges of the parts in the Model GT gearbox is also provided. By looking at this table, an operator can type in different ranges of frequencies and evaluate if there is a faulty part which is beyond the tolerance limits.

A sample vibration plot together with the filtered ones are presented in this work. It has been shown that depending on the frequency range, filtering can detect vibration of different part/parts contributing to the total vibration detected from the top of the gear-case.

Table 1. Frequencies in Model GT Gearbox

Parts	Frequencies (Hz)
Input Shaft Gear	720
1. Gear	328
2. Gear	502
3. Gear	611
4. Gear& Input Shaft	48
Reverse Gear	305
Bearing	170

## 2. EXPERIMENTAL SET-UP

The experimental rig which consists of a motor, an inverter, a gearbox, a transducer detecting acceleration, an amplifier, an Analog / Digital (A/D) converter and an IBM compatible 486 DX2-66 computer is shown in Fig.1 [6]. The components are explained below.

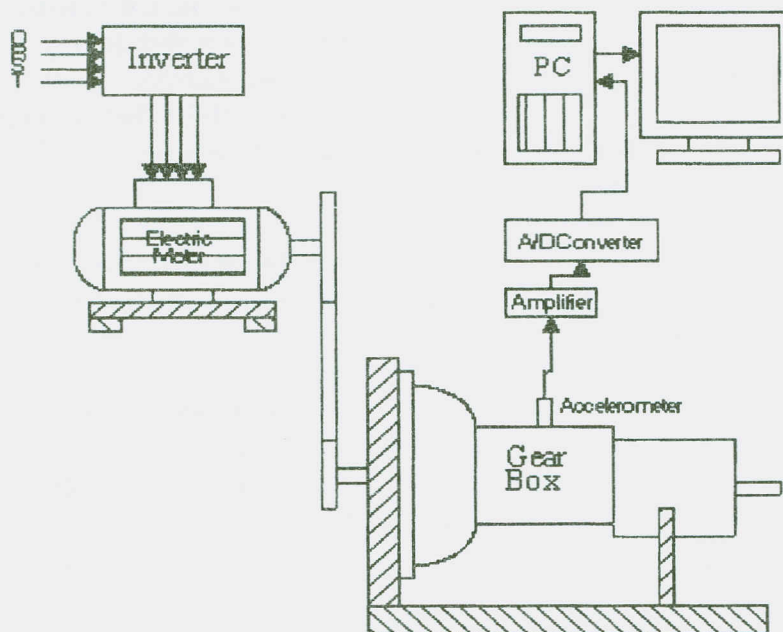


Fig.1 The Experimental Set-Up

**\*Motor:** An AC electric motor of 7.5 kW is used to drive the gearbox. Fixed speed of the motor is 2880 rpm.



**\*Inverter:** An inverter is used to vary the speed of the motor. With the aid of this instrument, it is possible to run the motor above its fixed speed. It can make the motor run as fast as 4000 rpm.

**\*Gearbox:** The gearbox used in the experiment is designed and produced by the Jeep Factory. It has four forward and one reverse gears together with the front wheel section.

**\*Transducer:** A Kistler made accelerometer of  $\pm 50g$  (where  $g=9.81 \text{ m/s}^2$ ) is used to do the measurement. It is a screw type and is mounted on the gearbox.

**\*Amplifier:** An amplifier is supplied together with the accelerometer. This amplifies a mV potential difference to the volt level. Maximum volt obtained from the amplifier is  $\pm 5V$  where  $+5V$  and  $-5V$  correspond to  $+50g$  and  $-50g$  respectively.

**\*A/D Converter:** An analog to digital converter is fitted into the computer to do the conversion. The highest A/D sampling rate is 100 kHz in Direct Memory Access (DMA) mode. Analog input ranges are from  $\pm 0.5V$  to  $\pm 10V$  bipolar. It is also possible to set the data acquisition card to unipolar.

**\*PC:** A 486 DX2-66 PC is used to do the measurement and diagnosis. The capacity of the computer is large enough to the job.

**\*Software:** A program in PASCAL is written to do the acquisition, process and display of data specifically for the factory use.

### 3. DATA ACQUISITION

When the gearbox is run at a certain speed, the program is also run and data is taken via A/D converter into the memory of the computer in arrays. Usually up to 3000 rows of data are taken at a time. During acquisition, set-time and get-time functions of PASCAL are used to find out the sampling rate which is used in filtering.

Before data acquisition, it is important to know the maximum output that the amplifier will produce. If it is e.g.  $\pm 0.8$  volts then the A/D converter input range must be set to  $\pm 1V$ . It is also important to make sure that data is taken fast enough not to lose the character of vibration.

### 4. FILTERING

A nonrecursive digital filter using the Fourier design techniques is employed to do the filtering. In fact, double filtering is carried out to have smoother data. A nonrecursive digital filter can be defined as [7].

$$y_k = c_m x_{k-m} + c_{m-1} x_{k-m+1} + \dots + c_0 x_k + \dots + c_{-m+1} x_{k+m-1} + c_{-m} x_{k+m} \quad (1)$$

where  $x$  represents the measured data and  $y$  is the output of the filter.  $k$  is the number of data. As can be seen from the equation to have one output  $y_k$ ,  $2m+1$  measured data are used together with the coefficients  $c$ . This is better illustrated in Fig.2.

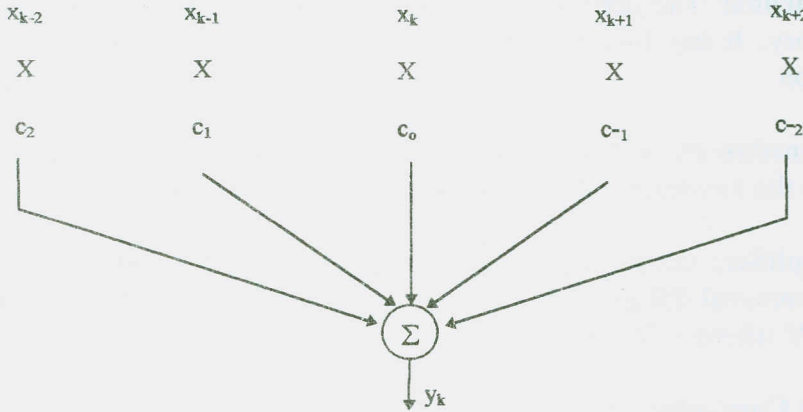


Fig.2 Nonrecursive Digital Filter

Eq.(1) can be written in a compact form as,

$$y_k = \sum_{i=-m}^m c_i x_{k-i} \quad (2)$$

It is shown by Williams that impulse response of a nonrecursive digital filter consists of the coefficients of the filter.

$$h_{(k)} = c_{(k)} \quad (3)$$

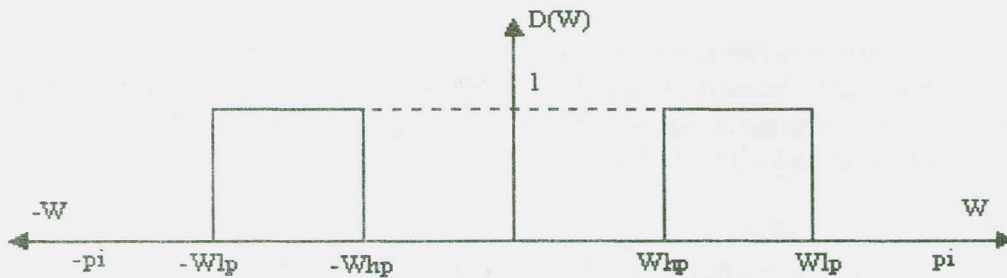


Fig.3 Cutoff Frequencies

Based on Fig.3, coefficients of a nonrecursive digital filter can be calculated by using [7],

$$h_i = \frac{1}{\pi} (\sin i\omega_{lp} - \sin i\omega_{hp}) \quad (4)$$

where  $\omega_{lp}$  and  $\omega_{hp}$  represent cut-off frequencies for low pass and high pass respectively. Typing  $\omega_{lp}$  and  $\omega_{hp}$  in the software filtering is carried out and the results are plotted.



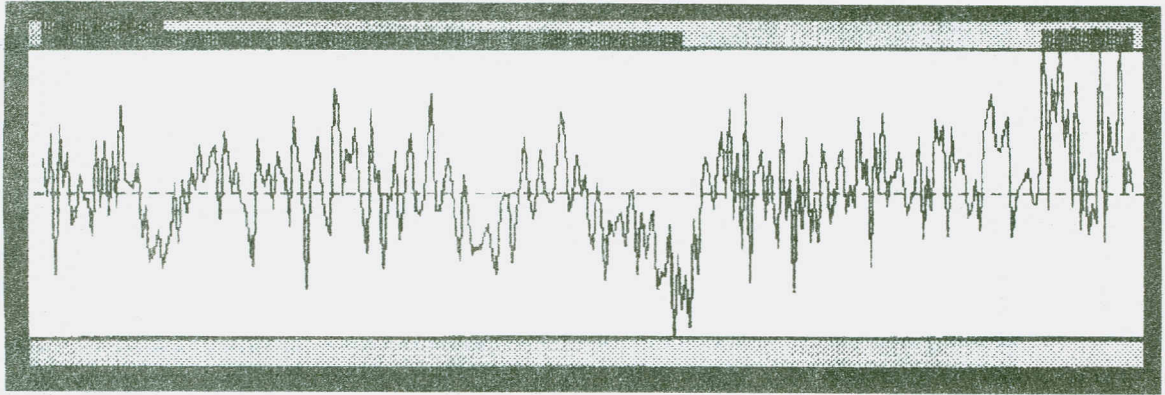


Fig.4 Total Acceleration of the Gearbox in Gear Three (RMS=50.582 m/s<sup>2</sup>).

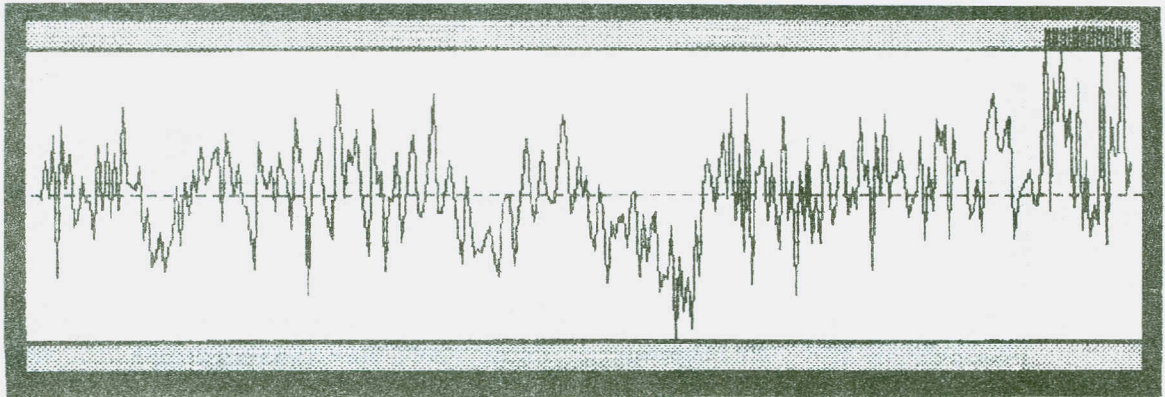


Fig.5 Filtered Plot of Total Acceleration for the Frequency Range 1100-0 Hz.  
(RMS=49.891 m/s<sup>2</sup>)

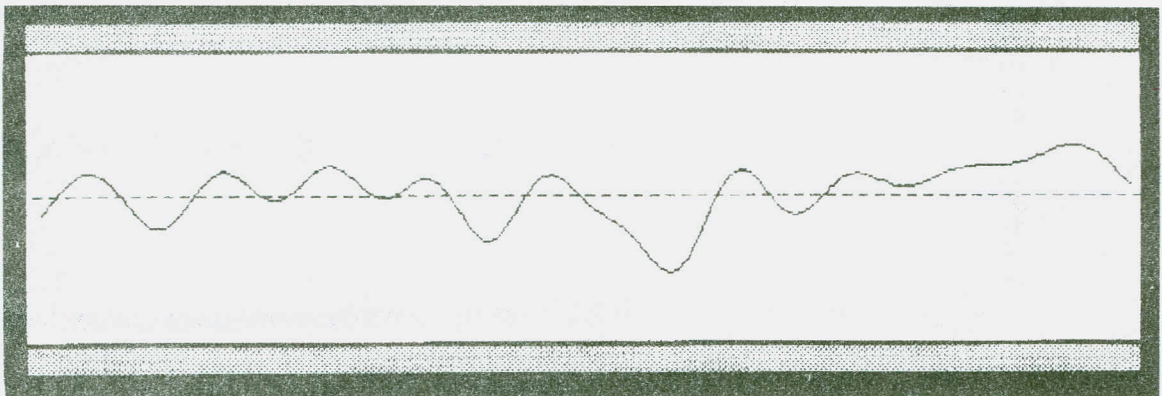


Fig.6 Filtered Plot of Total Acceleration for the Frequency Range 100-0 Hz.  
(Acceleration Produced by the Input Shaft, RMS=27.016 m/s<sup>2</sup>)

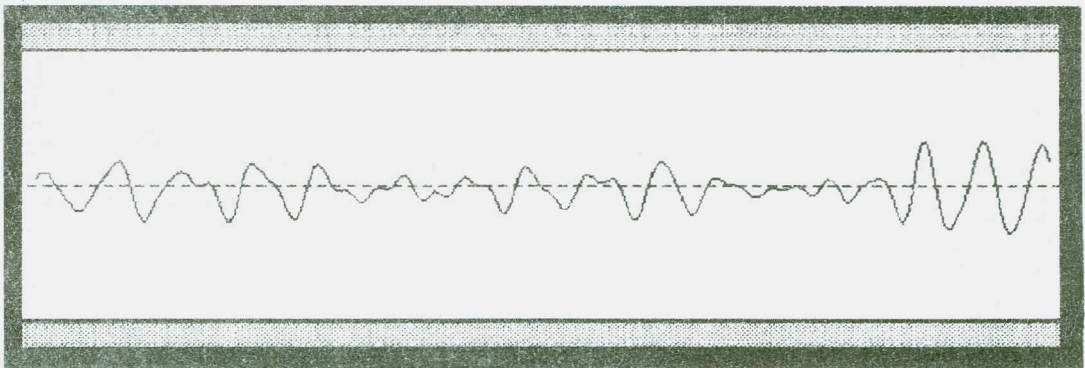


Fig.7 Filtered Plot of Total Acceleration for the Frequency Range 300-100 Hz.  
(Acceleration Produced by the Bearing, RMS=15.721 m/s<sup>2</sup>)

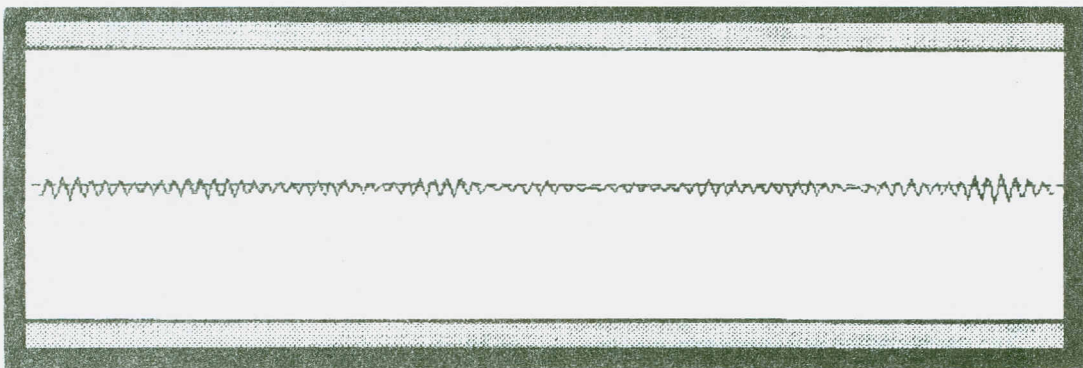


Fig.8 Filtered Plot of Total Acceleration for the Frequency Range 665-550 Hz.  
(Acceleration Produced by the Gear Three, RMS=6.73 m/s<sup>2</sup>)

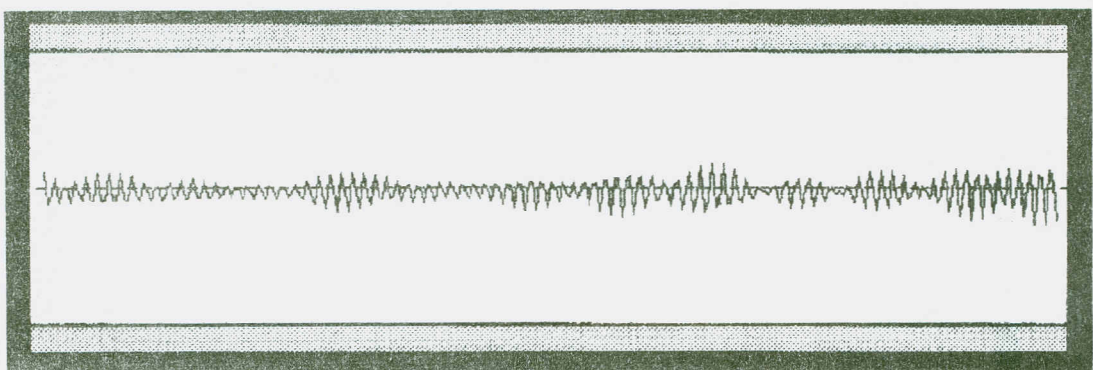


Fig.9 Filtered Plot of Total Acceleration for the Frequency Range 880-665 Hz.  
(Acceleration Produced by the Input Shaft Gear, RMS=18.911 m/s<sup>2</sup>)



## 5. EXPERIMENTAL RESULTS

Experimental data is obtained from the test-rig presented in Fig.1 in four forward gears, neutral and reverse sequently. For the sake of brevity, only a total acceleration ( $m/s^2$ ) plot when the box is in gear three is shown in Fig.4. This plot is a combination of the accelerations produced by the parts such as the driving shaft, gears and bearings. To evaluate vibration produced either by one part or a group of parts, the filter explained earlier is used. Because the sampling time is 0.00045 s, only frequencies up to 1100 Hz can be sampled in this plot. Filtered plot of Fig.4 for the frequency range between 1100 and 0 Hz is presented in Fig.5. This is almost identical to the original plot (Fig.4). This proves how efficiently the filtering program works.

To see the contribution of each part to the acceleration, filtering for 100-0 Hz, 300-100 Hz, 665-550 Hz and 800-665 Hz frequency ranges are done and results are presented in Fig.6,7,8 and 9 respectively. For the selection of the frequency ranges, data in Table 1 is considered. Above figures show contributions from the parts producing the total accelerations. As can be seen from the figures maximum contribution comes from the input shaft gear.

## 6. CONCLUSIONS

Frequency of the vibrations which are likely to be produced by the parts of the gearbox are determined. Actual vibration from the top of the gearbox-case is measured via an accelerometer. Measured data is filtered in different frequency ranges and contribution of acceleration from each part of the gearbox is determined. When the acceleration data is filtered between the maximum and zero frequencies the original data measured is obtained back. This proved the efficiency of the filter to do the analysis.

## ACKNOWLEDGEMENTS

The authors would like to thank for the facilities provided by the "K.K.K. 1013. Ordu Donatım Ana Tamir Jip Fabrikası (Jeep Factory)".

## REFERENCES

- [1] Umezawa,K., Houjoh,H., Maki,H., "Estimation of the Vibration of In-Service Gears by Monitoring the Exterior Vibration", Bull. JSME, 31, 588-592, 1988.
- [2] Kubo,A., Nakano,J., Chong,T.H., "A Method of Vibration Estimation of Gears with Unknown Gears Accuracy", Bull. JSME, 31, 416-422, 1988.
- [3] Güçlü, R., Ekrekli A., Tahralı, N., "En Küçük Kareler Metodu ile Bir Dişli Çark Sisteminin Titreşim Parametrelerinin Tahmin Hesabı", 6. Ulusal Makina Teorisi Sempozyumu, KTÜ, 485-493, Trabzon, 1993.
- [4] Güçlü, R., Ekrekli A., Tahralı, N., "Bilgisayar Destekli Bir Dişli Sisteminde Hata Analizi", 1. Sistem Müh. ve Savunma Uygulamaları Sempozyumu, KHO, 827-837, Ankara, 1995
- [5] Güçlü, R., Ekrekli A., Tahralı, N., "Dinamik Sistemlerde Non-recursive Dijital Filtirasyon", 7. Ulusal Makina Teorisi Sempozyumu, YTÜ, 535-544, İstanbul, 1995.
- [6] Bannister, B.R., Whitehead, D.G., "Transducers and Interfacing : Principles and Techniques", Van Nostrand Reinhold (UK), 1988.
- [7] Williams, C.S., "Designing Digital Filters", Prentice, Hall International Editions, 1986.