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ECOLE D'INGENIEURS

International Franco-Canadian Double Diploma Program
In Automated Production Engineering
Promotion 2003

Projet de fin d’études
Intelligenter Radsatz 2000+

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A very nice thank you to Mr. Bernhard Lang who was my supervisor during my stay at Siemens. Thanks to his cooperation and his support, I could well achieve this “Projet de fin d’études” in Germany.

Thank you also to the members of the “Intelligenter Radsatz 2000+” team who made me feel that the good work can be made within a strong cooperation of a team, especially during the trip to Berlin where we gathered to make measurements.

Jonathan Grandidier

Intitulé du stage

Project « Intelligent Wheelset ». Online measurements, reports, and diagnosis of defects of the wheelset of ICE (German high speed train) by analysis, conception and application of evaluation algorithms.

Title of the Internship and Work done

Roues Intelligentes 2000+

Mesure et analyse de défauts sur les roues de train ICE par mesure d'impact sonore au banc d'essai de Munich Perlach et de la Deutsche Bahn. Report des erreurs du programme de test. Analyse des mesures par algorithmes et methodes par traitements du signal.

Intelligent Wheelset 2000

Measurements and analysis of defects of an ICE train by sound impact at the testing rooms of Munich Perlach and of the Deutsche Bahn. Reporting of the errors of the test program. Analysis of the measurements by test algorithms and methods of signal processing.

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Preface

I am currently doing my „Projet de fin d'études" at Siemens in the division Corporate Technology located in Munich Perlach in Germany. During this stay, I am mostly involved in a project of about 20 people on Munich Siemens site. This project is called "Intelligenter Radsatz 2000+". The other partners of this project are "Deutsche Bahn", "FAG" and the "IZFP". This project is spread on 3 years from November 2001 to 2004. Its goal is to detect the defects of a wheelset of an ICE (German high speed train) in order to determine the lifetime of the wheelset. To detect the defects, we get some signals caused by the wheelset when running at different speeds and with different loads. My main tasks in this project is to get the different signals coming from the wheelset simultaneously using the results of another project called "SiCOM" and developed in another department of Siemens in Erlangen and to perform some algorithms in order to analyse the signals we get from the wheelset. As we get several signals, I do not analyse each of them in detail but compare them. Some other members of the team more specialized in a specific sensor analyse their signals more in detail.

In this report, I will first provide a short overview of Siemens Corporate Technology and I will then develop the tasks I was involved in. I will present the SiCOM system, the program that gets several signals simultaneously and explain how to use it. I will then describe in detail the project "Intelligenter Radsatz", explain how to use some MATLAB programs that help for the analysis of the signals and also focus on the determination of the resonance frequency of the wheelset and some comparison between the signals depending on different factors such as the defects, the load or the velocity of the wheelset.

1 Siemens Corporate Technology

1.1 Corporate Technology

1.1.1 Mission

Siemens Corporate Technology is a whole division of Siemens. Its mission is to secure the technological future of the Company and to increase the competitiveness of Siemens in close cooperation with the Business Groups by:

- Research, development and consulting in strategically important technologies (core technologies)
- Development of business scenarios and identification of new applications, markets and businesses
- Safeguarding the Company's interests in the area of Intellectual Property
- Corporate functions of Quality Management, Environmental Affairs & Technical Safety, Standardization & Regulation, Information Research Center
- Developing and training future technical managers

1.1.2 Employees

The entire number of employees at Siemens is about 450 000 all over the world. In the division Corporate Technology, the number of employees is 1870 and divided as shown on figure 1.1.

Figure 1.1: Corporate Technology Employees

1.1.3 Locations

Corporate Technology is spread in different sites of Siemens as shown on figure 1.2:

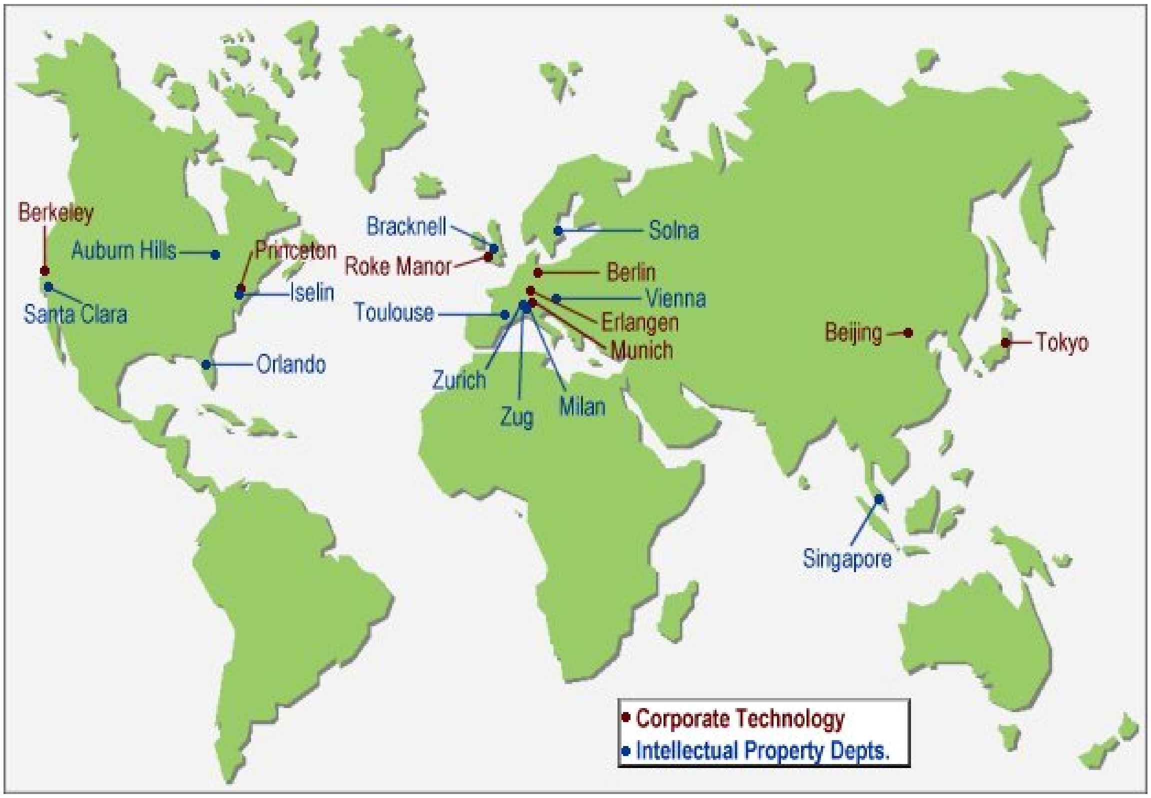


Figure 1.2: Corporate Technology Locations

As we can see on the figure 1.2, Siemens Corporate Technology is quite international as it is located in 3 continents. Its main focus is research and development. The site where I am operating is the one located in Munich Germany, in particular the department IC4 of Corporate Technology, Information and Communications.

1.2 Information and Communications department

Information and communications is a department of Corporate Technology mostly located in Munich.

Its purpose is to accomplish things, and to have an environment that supports our efforts--including the right technology.

That's why the I&C technologies are designed to make life easier.

- Smart networks ensure that networks and terminals work together intelligently. The department CT IC focus on applications and services in mobile networks, on videocommunication, mobility and quality of service in the Internet, on traffic engineering and network planning.

- With the cryptographic know-how, CT IC protects data and authenticates communicating parties for secure transactions.
- CT IC develops intelligent autonomous systems, with new methods modeled on human thinking, and applications such as prognosis, fraud detection, and knowledge discovery. Intelligent software agents and robots take over routine tasks.
- Since CT IC believes that technology is here to serve us, it facilitates human-machine interaction using gestures and speech recognition, and invest in user interface design emphasizes ease-of-use.
- The knowledge management team works to ensure that knowledge is available to anyone who needs it so that we do not waste our time reinventing the wheel.

2 Research Project "Intelligenter Radsatz 2000+"

2.1 Description of the project

2.1.1 Overview

The project "Intelligenter Radsatz 2000+", also called "Intras 2000+" is a research project over 3 years from November 2001 to 2004. It is concerning the online monitoring and diagnosis of the wheelsets of the German high-speed train ICE (Inter City Express) represented on the figure 2.1.

Figure 2.1: German high speed train ICE3

2.1.2 Project partners

This project is performed in collaboration with different companies that are Siemens, the "Deutsche Bahn", FAG and FIZP. In Siemens, about 20 people of several departments are involved including the department IC4.

Die Bahn DB

Fraunhofer IZFP Institut Zerstörungsfreie Prüfverfahren

S

FAG

Figure 2.2: Different partners in the project "Intelligenter Radsatz"

2.1.3 Purpose of the project

The main purpose of this project is to measure, perform a diagnosis and an on-line monitoring of signals corresponding to the wheelset by analysis, conception and application of evaluation algorithms. In the long term, the signals we get will enable to determine the lifetime of an ICE wheel. At Siemens, some measurements are currently done with several sensors, however a part of the project is to determine which sensor is the best for our purpose in order to be able, for reasonable costs, to install a sensor on each wheel or set of wheels of the train. The signals we get come from a wheelset as shown on the figure 2.3.

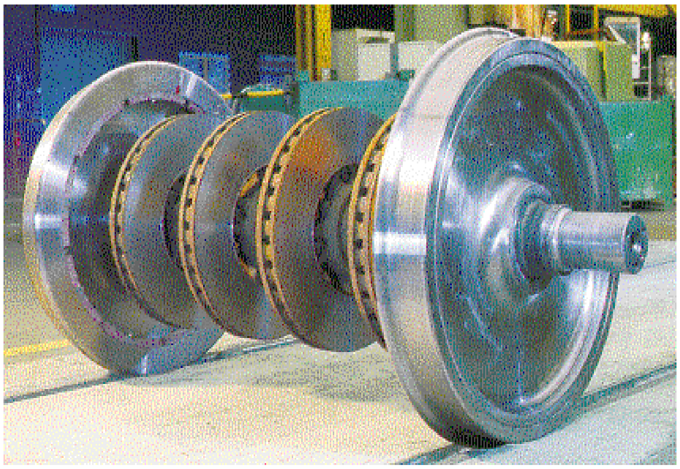


Figure 2.3: Wheelset on which the measurements are performed

2.2 Realisation

To do some measurements in order to analyse the signal, the ideal situation would be to do tests on the wheels of a real running train. As this solution is very expensive and there are several tests to do, some tests are done on a single wheel or on a wheelset with an artificial rotating motor that makes the wheel or the set of wheels turn as if it was in real conditions.

There is a testing room that was built in Munich.

There is also a more advanced testing room provided by the partner “Deutsche Bahn” which is located in Kirchmöser near Berlin. This test environment is closer to a real train than the test rig in Munich.

2.2.1 Testing Room on Siemens site in Munich

The testing room that was built on the Siemens site in Munich can drive a single wheel. There is a drive with motor and axis on which the train wheel is. There is also a smaller wheel that represents the railway. The railway wheel is attached to a hydraulic piston that can create a pressure between the railway wheel and the train wheel to simulate the weight of the train. Figure 2.4 describes the testing room on Siemens site in Munich.

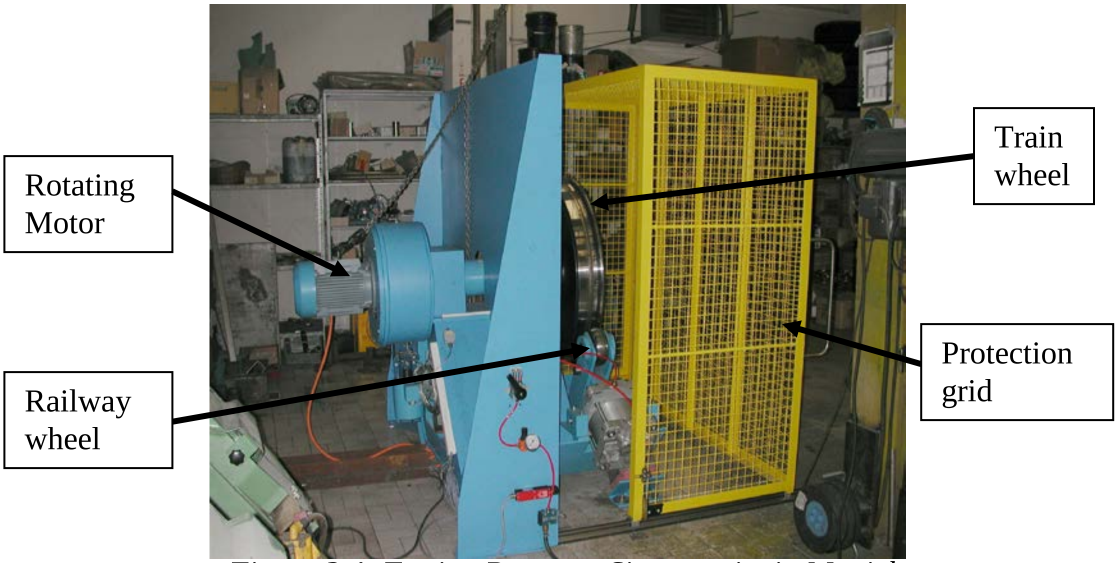


Figure 2.4: Testing Room on Siemens site in Munich

2.2.2 <u>Testing room on Deutsche Bahn site in Kirchmöser near Berlin</u>

The testing room that was built on the Deutsche Bahn in Kirchmöser near Berlin is very advanced. It can rotate a whole wheelset on a 1.5 times larger wheel to have a better simulation of the railway. The load of the wheelset can change. We usually set it to 6 tons or 10 tons.

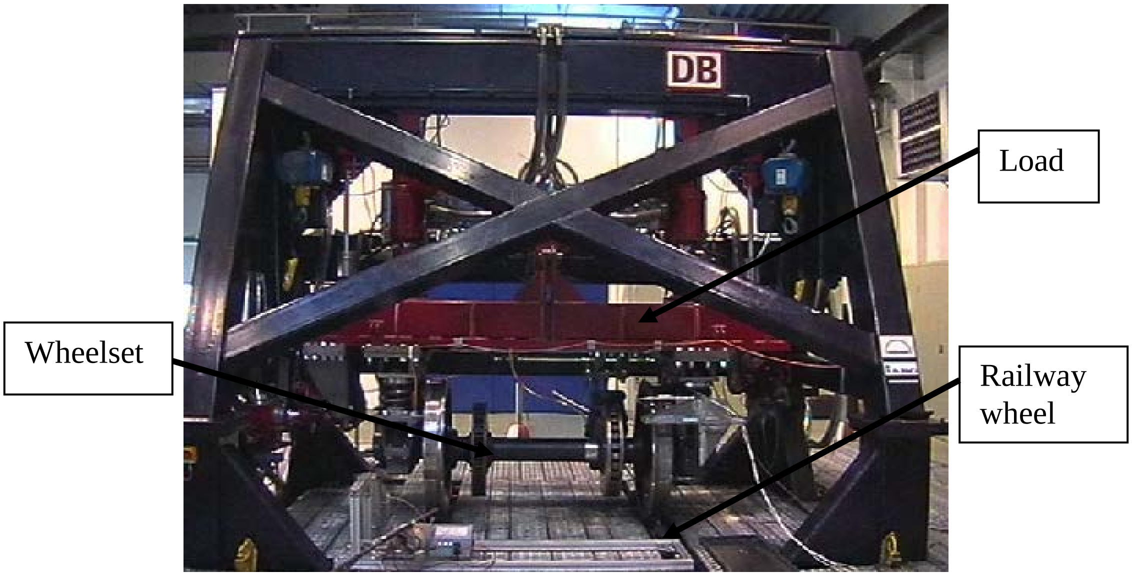


Figure 2.5: Testing room at the Deutsche Bahn site in Kirchmöser

2.2.3 <u>Tests on a real train</u>

Our team did not do tests on a real train. After having carried out analyses on test rigs, tests on a real train are planned in November 2003 on a Siemens site in north Germany. In this case, the team will be able to perform tests that will be very close to the reality.

Moreover, we could get some data of other measurements on a real train by Siemens Austria.

2.2.4 Artificial defects

To understand the influence of the defects on the wheel, we create artificial defects such as:

- Slits
- Holes
- Flats

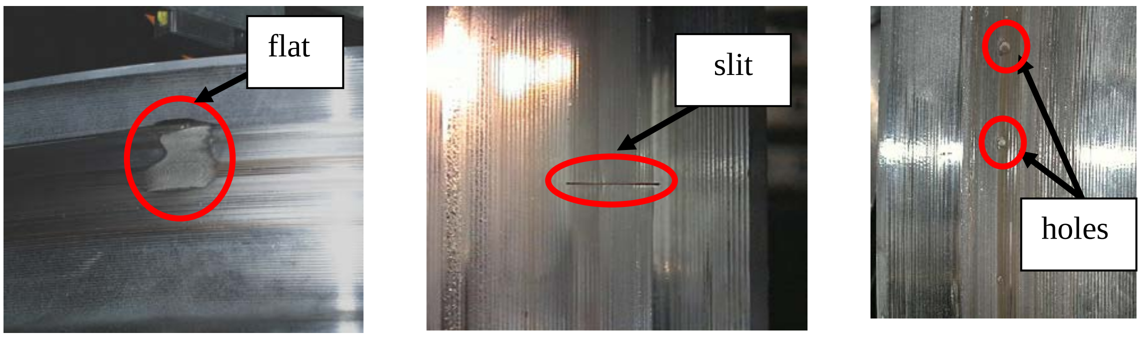


Figure 2.6: Example of created flat, slit and holes on the wheel

On the preceding figures, we can see a flat and a slit created artificially. Those defects correspond to defects that would appear naturally with the use of the wheel. The first step in this project is to be able to detect those artificial defects in a test environment so that we will be able in the future to detect the defects on the wheels of a running train.

2.3 Acquisition of the data

2.3.1 Sensors

To get the data, each member of the team places a sensor on a specific place of the wheelset:

- Eddy current sensors on the surface of the wheel to measure the oscillations of the wheel

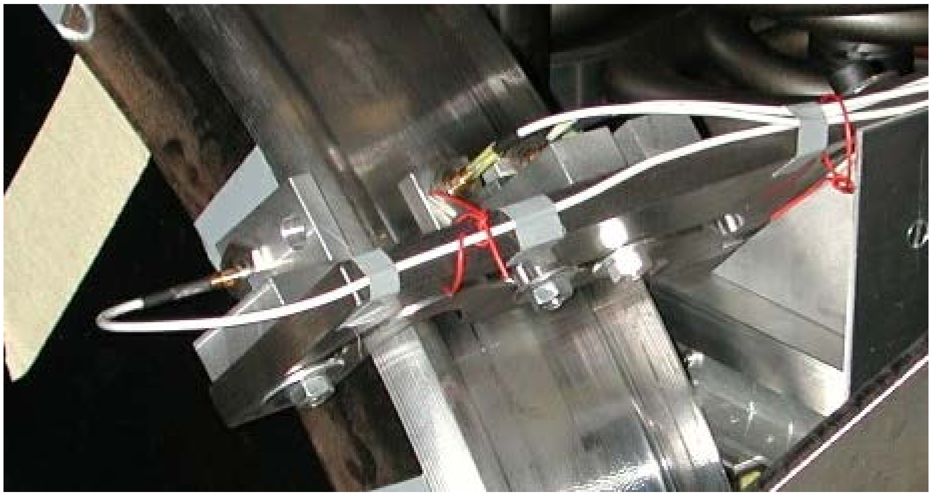


Figure 2.7: Eddy current sensor

- Vibration sensor on the fixed part (bearing)

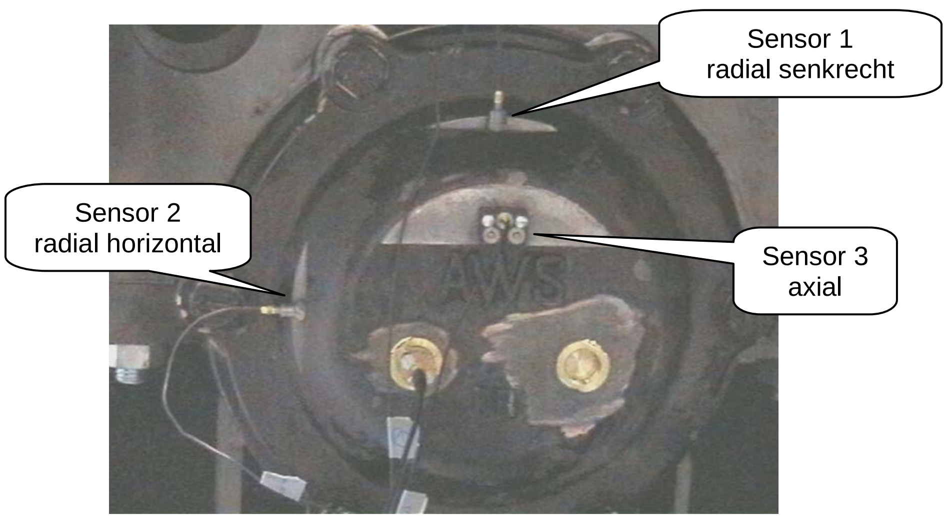


Figure 2.8: Vibration sensors on the fixed part

- Vibration radio sensor on the fixed part for high frequencies

- Vibration sensor on the wheel with radio transmission for the vibrations of the wheel.

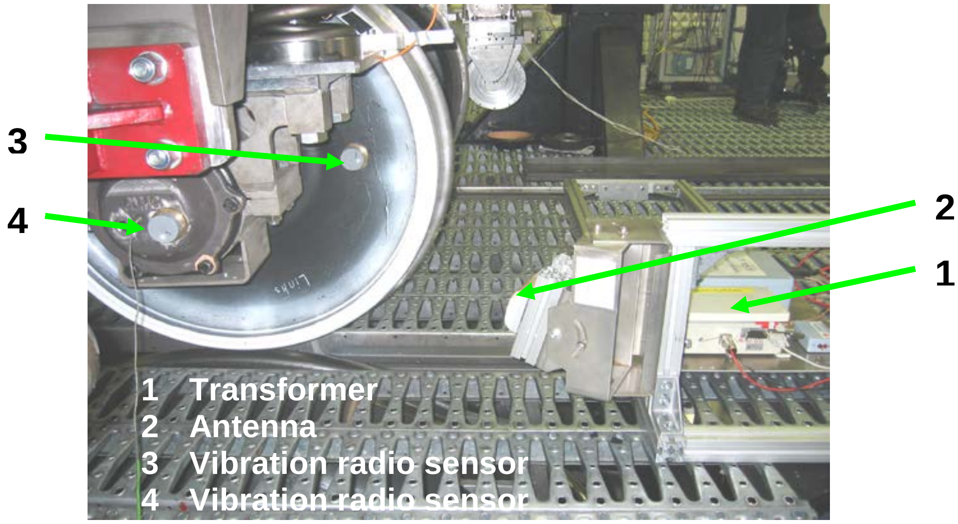


Figure 2.9: Vibration radio sensor

- Optical sensor for the trigger

2.3.2 Data

Each sensor is connected to an analog-digital converter called I/Onode. Each I/Onode can get until eight channels. The I/Onodes are connected by firewire connection together and to an Industrial PC. On the PC, a software called “SiCOM System” records the data of all the channels of the I/Onodes simultaneously. We are then able to analyse the recorded data with a program such as MATLAB.

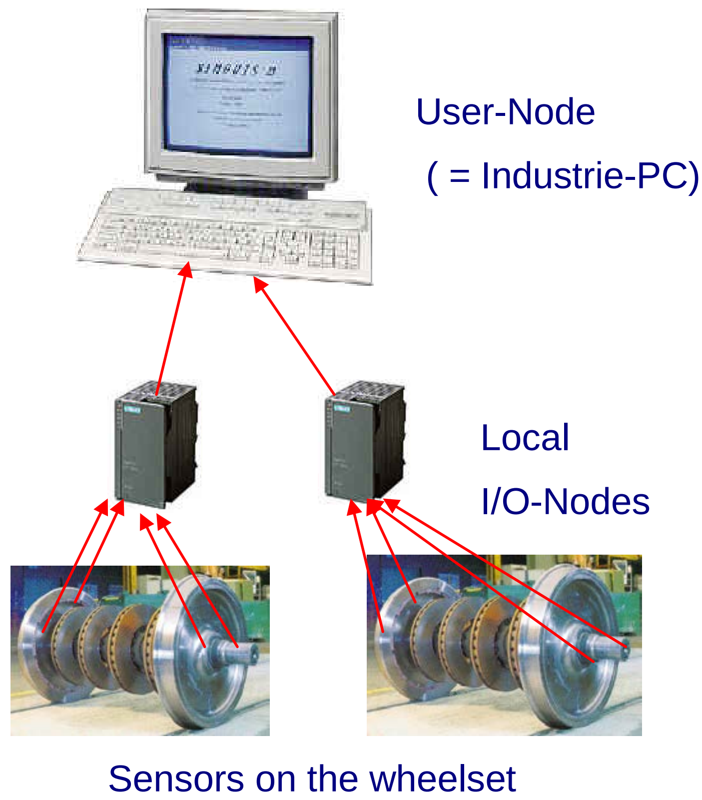


Figure 2.10: Connection between the sensors, the I/Onodes and the PC

3 The SiCOM System

On this part, we will explain in further details the hardware and the software part of the project and talk about the SiCOM system.

The development of the SiCOM system is an independent project. However, this system which is still under development has an important role in the “Intelligenter Radsatz” project as it is used to record the data coming from the wheelset simultaneously. Simultaneous recording enables a better analysis as we can compare signals exactly at the same time.

3.1 Introduction of the SiCOM system

The measurement system that acquires the data from the sensors is called SiCOM system. It is developed by other teams located in Siemens in Erlangen-Germany, in Poland and in China.

The hardware part includes the I/Onodes where the channels for the signals come from and the Industrial PC.

The software part is the SiCOM program written in C++. It can record the data in binary format and then convert it into an ASCII format to be easily read by MATLAB or any other analysis program.

One of the parts of the SiCOM project is to test the SiCOM system, to carry out some tests and regression tests and to report the errors found in the SiCOM system to the team in Erlangen in order to improve it.

3.2 Hardware

To get the data from the sensor to the PC, we first use a small box called I/Onodes in order to convert the analog signal into a digital signal. Each I/Onodes can get up to eight channels corresponding to eight different signals. As we have more that eight signals, we use several I/Onodes and connect them together by a firewire bus system.

Figure 3.1: I/Onode used by the SiCOM system

One of the I/Onode is connected to an industrial PC on a firewire card. With the firewire connection, we can get a recording time stamp of 25 µs for the signals of up to 40 kHz.

3.3 Software

The SiCOM program is used to set parameters, to view the signals, to record them and to analyse them. The analysis function is not available yet and is under development.

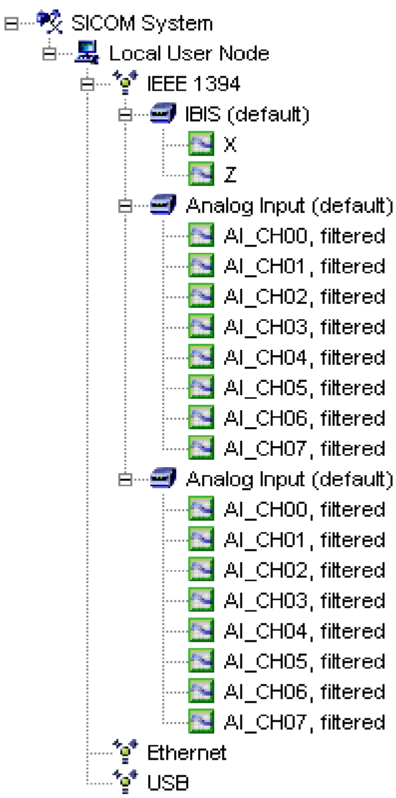
In this part, we will describe and explain how to use the SiCOM program, which is a major part of the SiCOM system.

3.3.1 Start SiCOM program

To start the SiCOM program, we have to respect the following order:
- Switch on the PC
- Switch on the I/Onode boxes
- Start the SiCOM program by double-clicking on the SiCOM Xtools icon

Figure 3.2: Icon to start the SiCOM program

After the SiCOM program is started, the channels of the I/Onodes appear as shown on figure 3.3:



If some channels are missing, it means they are not recognized by SiCOM program.
In this case, the program or the I/Onode boxes have to be stopped and restarted.

Figure 3.3: Channels of the I/Onodes

3.3.2 SiCOM program menus

The following menus are at the top of the screen:

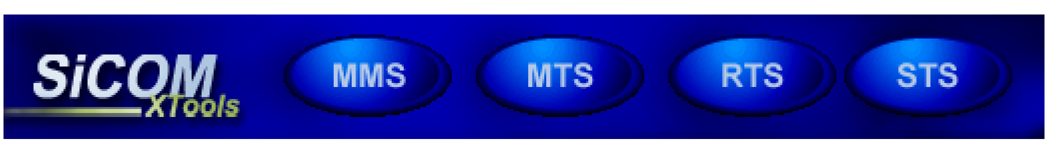


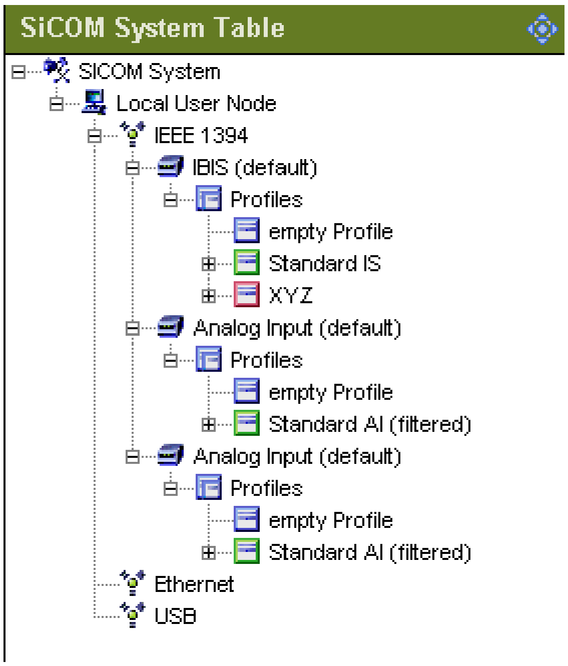
Figure 3.4: Four main functions in the SiCOM program

Those menus (MMS, MTS, RTS and STS) can be activated and deactivated by clicking on them. Each button corresponds to a part of the SiCOM program. On the next pages of this report, there is a detailed explanation of each button.

3.3.2.1 MMS: Management System

a) Select and deselect a profile

This menu allows to activate and deactivate channels:



By right-clicking on the profile corresponding and on „Deselect/Select profile“, it is possible to select or deselect all the channels of an I/Onode box.

Figure 3.5: Profiles of the SiCOM system

b) Select and deselect a channel

It is also possible to deselect or select only one channel by clicking on it from the following screen:

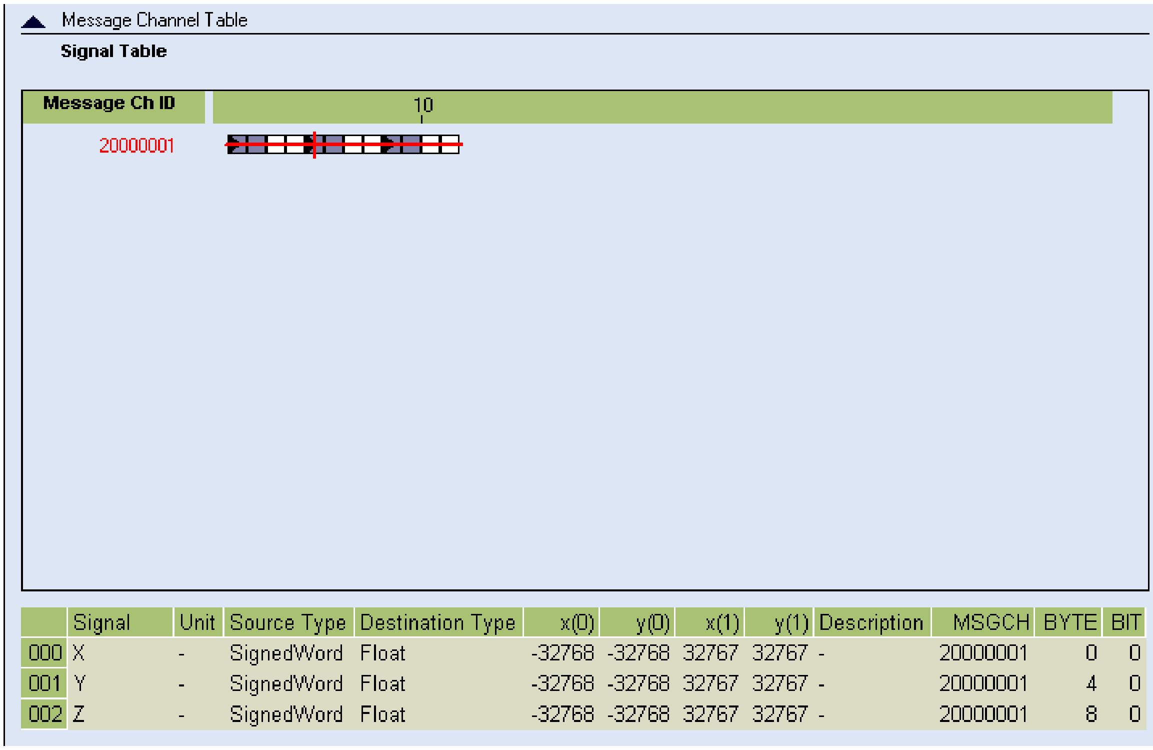
Signal		Profile		ION		Bus	
State	Name	State	Name	Name	ID	Name	ID
	X		Standard IS	IBIS (default)	000001	IEEE 1394	1
	Z						
	XYZ		XYZ	IBIS (default)	000001	IEEE 1394	1
	AI_CH00, filtered		Standard AI (filtered)	Analog Input (default)	000006	IEEE 1394	1
	AI_CH01, filtered						
	AI_CH02, filtered						
	AI_CH03, filtered						
	AI_CH04, filtered						
	AI_CH05, filtered						
	AI_CH06, filtered						
	AI_CH07, filtered						
	AI_CH00, filtered		Standard AI (filtered)	Analog Input (default)	000007	IEEE 1394	1
	AI_CH01, filtered						
	AI_CH02, filtered						
	AI_CH03, filtered						
	AI_CH04, filtered						
	AI_CH05, filtered						
	AI_CH06, filtered						
	AI_CH07, filtered						

Figure 3.6: Selecting and deselecting channels

This screen is obtained from MMS by clicking on „Master Signal List“ and „View“, then selecting the buttons „ALL“.

c) Install a channel in a profile

A channel is installed by the following procedure:
- In the MMS menu, click on MSGCH signal editor.
- Highlight „Signal Table“
- Drag and drop the profile where the channel is missing (eg: Standard IS)
- Double-click on the starting byte where the channel will be stored
- Enter the parameters of the channel and save



	Signal	Unit	Source Type	Destination Type	x(0)	y(0)	x(1)	y(1)	Description	MSGCH	BYTE	BIT
000	X	-	SignedWord	Float	-32768	-32768	32767	32767	-	20000001	0	0
001	Y	-	SignedWord	Float	-32768	-32768	32767	32767	-	20000001	4	0
002	Z	-	SignedWord	Float	-32768	-32768	32767	32767	-	20000001	8	0

Figure 3.7: Coding of a channel on 12 bytes

3.3.2.2 MTS: Monitoring System

<u>a) View channels separately on the screen</u>

When the monitoring system is activated, we can see an on-line monitoring of a channel. The desired channel has to be dragged and dropped from the signal list to the monitoring screen.

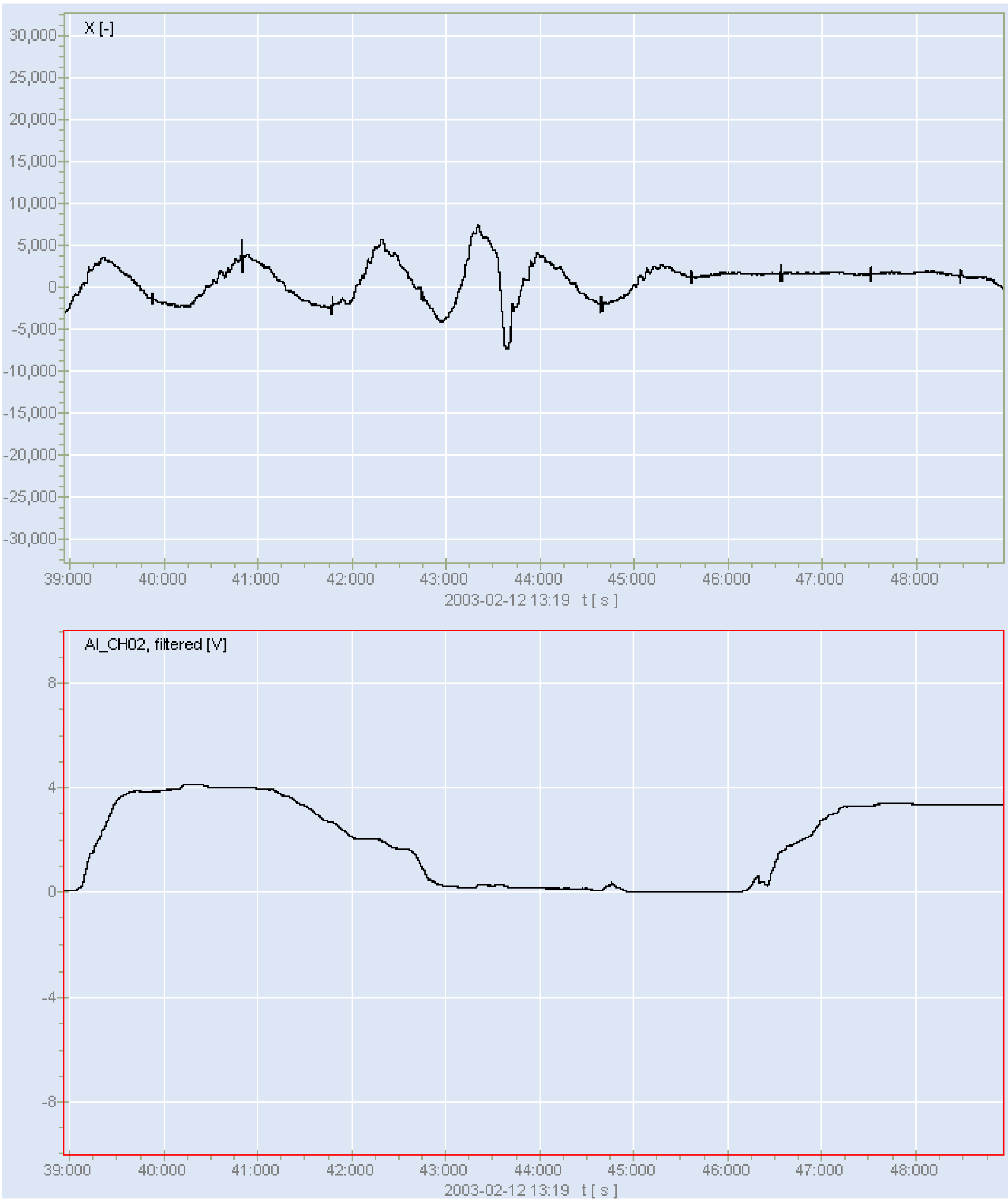


Figure 3.8: Example of an online viewing of the channels

Up to 5 channels can be seen separately on the same screen.

b) View channels on the same graph

It is possible to view channels on the same graph by drag and drop a channel on the same place of a channel that is already being visualized.

c) Change the scale

To change the scale, we right-click on the values of the X-axis or the Y-axis. The 2 following choices are then available:

- Autoscale: it will adapt the scale to the current visualized graph automatically.
- Enter the range manually.

d) Zooming function

To zoom on a graph, we select the part we want to zoom on with the left button of the mouse. It is possible to zoom-out by right click on the graph and select the zoom-out function.

3.3.2.3 RTS: Runtime System

This function is not available yet and is under development. It corresponds to the online analysis of the signal. For now, as we need this function, we replace it by other signal analysis programs such as MATLAB.

3.3.2.4 STS: Storage System

In the STS menu, to store the data of one or several channels, the desired channels have to be dragged and dropped in the storage screen shown on figure 3.9.

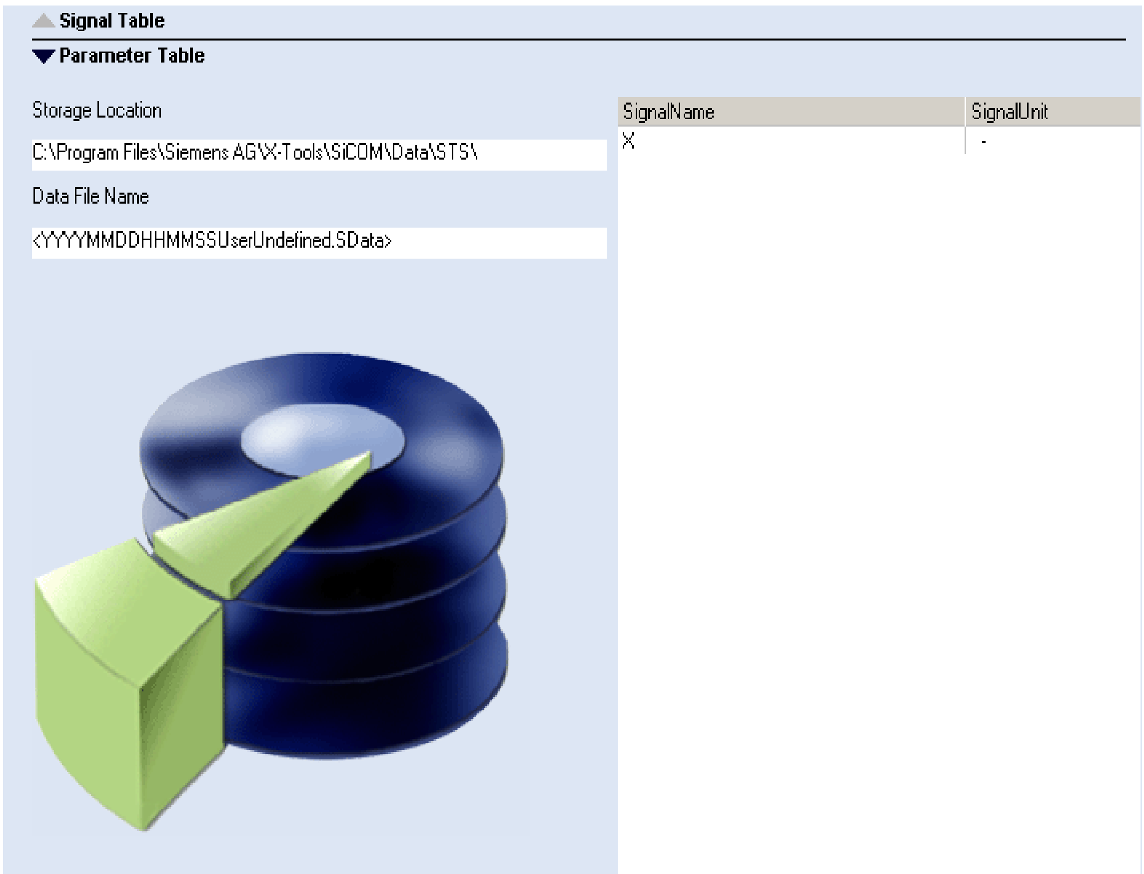


Figure 3.9: Recording menu

Then, after clicking on parameter table, we can enter parameters and save a profile containing one or several channels.

<u>a) Record one profile</u>

To record channels from a saved profile, we have to click on „Storage Profile Control“ and drag and drop the desired profile from the storage profile list.

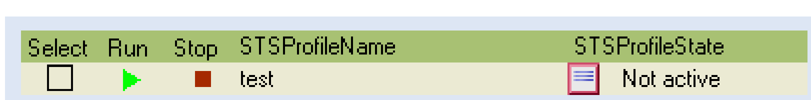


Figure 3.10: Running menu for recording a profile

The profile can be run and stopped with the menu shown on figure 3.10 and the data is stored in a file specified in the parameter table.

b) Record many profiles at the same time

It is possible to record many profiles from the same folder at the same time.

For example, in the following picture, we can record the 2 profiles „Jonathan1“ and „Jonathan2“ at the same time because they are in directory „ParJonathan“.

The directory „ParJonathan“ has to be dragged and dropped in the screen of the „Storage profile control“.

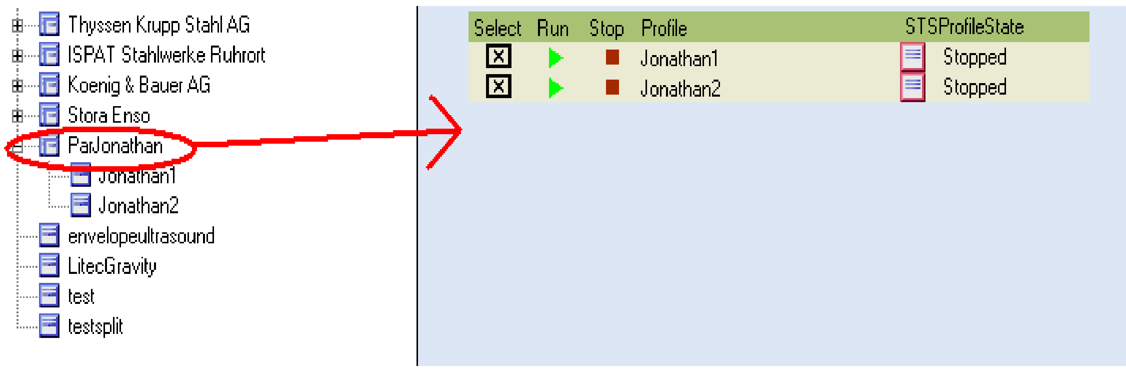


Figure 3.11: Recording of 2 profiles at the same time

After that, we can select which channel we want to record by selecting them and click on „Record selected channels“. Then, the 2 profiles are saved independently.

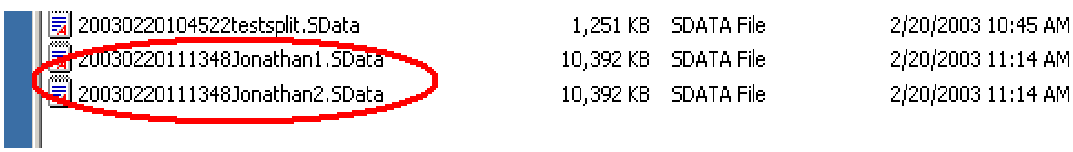


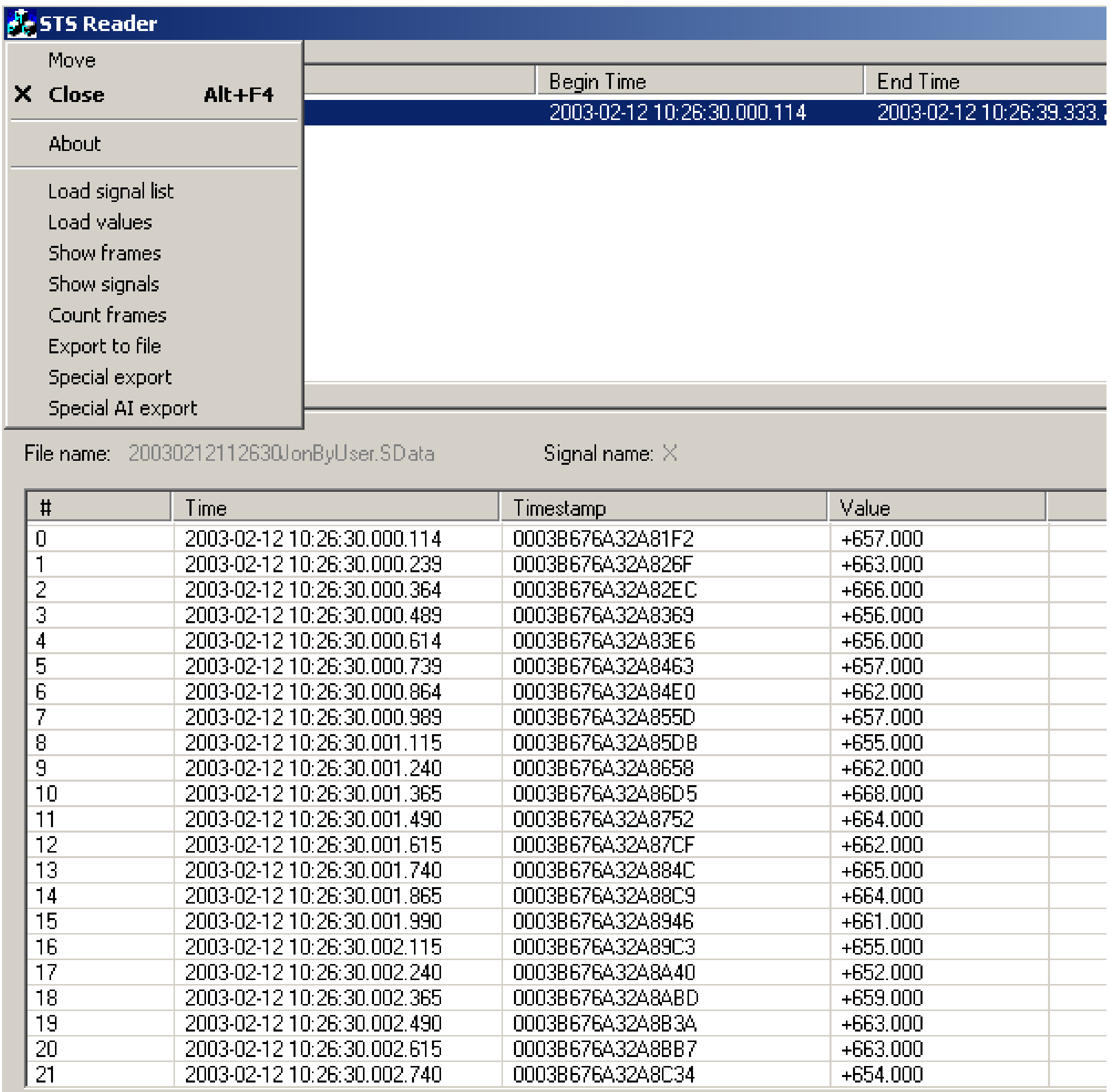
Figure 3.12: Independent storage of each profile as a binary file

3.3.3 Read Data

To read the stored data, we start the STS Reader program from the windows desktop with the icon:

Figure 3.13: Icon of the SiCOM STSReader to convert binary files into ASCII files

Clicking on the icon on the top left of the window, we can open a pull-down menu and select one of the functions, for instance “Load signal list”.



#	Time	Timestamp	Value
0	2003-02-12 10:26:30.000.114	0003B676A32A81F2	+657.000
1	2003-02-12 10:26:30.000.239	0003B676A32A826F	+663.000
2	2003-02-12 10:26:30.000.364	0003B676A32A82EC	+666.000
3	2003-02-12 10:26:30.000.489	0003B676A32A8369	+656.000
4	2003-02-12 10:26:30.000.614	0003B676A32A83E6	+656.000
5	2003-02-12 10:26:30.000.739	0003B676A32A8463	+657.000
6	2003-02-12 10:26:30.000.864	0003B676A32A84E0	+662.000
7	2003-02-12 10:26:30.000.989	0003B676A32A855D	+657.000
8	2003-02-12 10:26:30.001.115	0003B676A32A85DB	+655.000
9	2003-02-12 10:26:30.001.240	0003B676A32A8658	+662.000
10	2003-02-12 10:26:30.001.365	0003B676A32A86D5	+668.000
11	2003-02-12 10:26:30.001.490	0003B676A32A8752	+664.000
12	2003-02-12 10:26:30.001.615	0003B676A32A87CF	+662.000
13	2003-02-12 10:26:30.001.740	0003B676A32A884C	+665.000
14	2003-02-12 10:26:30.001.865	0003B676A32A88C9	+664.000
15	2003-02-12 10:26:30.001.990	0003B676A32A8946	+661.000
16	2003-02-12 10:26:30.002.115	0003B676A32A89C3	+655.000
17	2003-02-12 10:26:30.002.240	0003B676A32A8A40	+652.000
18	2003-02-12 10:26:30.002.365	0003B676A32A8ABD	+659.000
19	2003-02-12 10:26:30.002.490	0003B676A32A8B3A	+663.000
20	2003-02-12 10:26:30.002.615	0003B676A32A8BB7	+663.000
21	2003-02-12 10:26:30.002.740	0003B676A32A8C34	+654.000

Figure 3.14: Loading of a signal of a stored profile

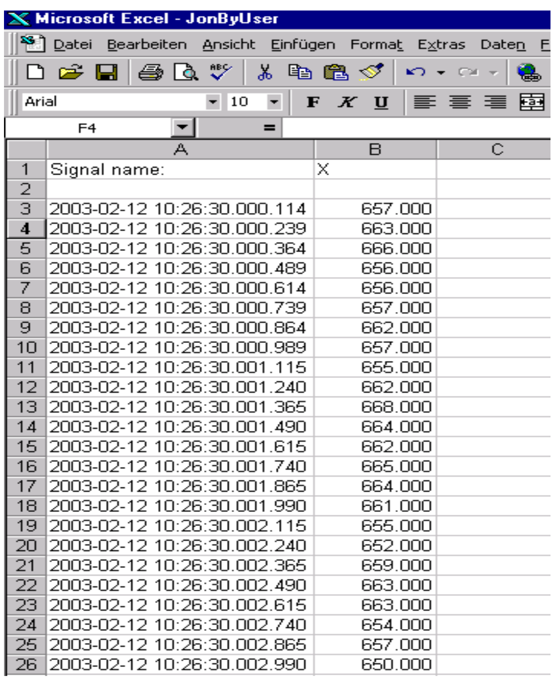
- The following data is saved in a text file:

Signal name: X

2003-02-12 10:26:30.000.114	+657.000
2003-02-12 10:26:30.000.239	+663.000
2003-02-12 10:26:30.000.364	+666.000
2003-02-12 10:26:30.000.489	+656.000
2003-02-12 10:26:30.000.614	+656.000
2003-02-12 10:26:30.000.739	+657.000
2003-02-12 10:26:30.000.864	+662.000
2003-02-12 10:26:30.000.989	+657.000
2003-02-12 10:26:30.001.115	+655.000
2003-02-12 10:26:30.001.240	+662.000
2003-02-12 10:26:30.001.365	+668.000
2003-02-12 10:26:30.001.490	+664.000
2003-02-12 10:26:30.001.615	+662.000
2003-02-12 10:26:30.001.740	+665.000
2003-02-12 10:26:30.001.865	+664.000
2003-02-12 10:26:30.001.990	+661.000
2003-02-12 10:26:30.002.115	+655.000
2003-02-12 10:26:30.002.240	+652.000
2003-02-12 10:26:30.002.365	+659.000
2003-02-12 10:26:30.002.490	+663.000

Figure 3.15: Example of stored data after conversion into ASCII format

It can be read by Microsoft Excel:



	A	B	C
1	Signal name:	X	
2			
3	2003-02-12 10:26:30.000.114	657.000	
4	2003-02-12 10:26:30.000.239	663.000	
5	2003-02-12 10:26:30.000.364	666.000	
6	2003-02-12 10:26:30.000.489	656.000	
7	2003-02-12 10:26:30.000.614	656.000	
8	2003-02-12 10:26:30.000.739	657.000	
9	2003-02-12 10:26:30.000.864	662.000	
10	2003-02-12 10:26:30.000.989	657.000	
11	2003-02-12 10:26:30.001.115	655.000	
12	2003-02-12 10:26:30.001.240	662.000	
13	2003-02-12 10:26:30.001.365	668.000	
14	2003-02-12 10:26:30.001.490	664.000	
15	2003-02-12 10:26:30.001.615	662.000	
16	2003-02-12 10:26:30.001.740	665.000	
17	2003-02-12 10:26:30.001.865	664.000	
18	2003-02-12 10:26:30.001.990	661.000	
19	2003-02-12 10:26:30.002.115	655.000	
20	2003-02-12 10:26:30.002.240	652.000	
21	2003-02-12 10:26:30.002.365	659.000	
22	2003-02-12 10:26:30.002.490	663.000	
23	2003-02-12 10:26:30.002.615	663.000	
24	2003-02-12 10:26:30.002.740	654.000	
25	2003-02-12 10:26:30.002.865	657.000	
26	2003-02-12 10:26:30.002.990	650.000	

Figure 3.16: Example of using another program for a better treatment of the data

The STS Reader program is explained in further details in part 4 of “Measurement Campaign at the Deutsche Bahn in Kirchmöser” (Refer to bibliography [Grandidier2003a]).

3.4 Regression test

For a better improvement of the SiCOM system, some regression tests were done and were sent directly to the responsible of the programming team.

The table 3.1 shows an example of a regression test.

Task Nr.	**Description**	**Release 13/2/2003**	**Release 3/3/2003**	**Tested by / Date**
1.	All the I/Onodes are recognized at first start of SiCOM programm	NO	NO	Grandidier 3/3/2003
2.	Value measured with SiCOM program corresponds to the values entered in the channels of the I/Onodes	NO	YES	Grandidier 3/3/2003
3.	Settings are not changing between 2 runs of the SiCOM programm.	NO	YES	Grandidier 3/3/2003
4.	All datas are recorded during recording mode	NO	YES	Grandidier 3/3/2003
5.	Functions „by timer“, „by signal“ and „by Date&Time“ working in STS mode	NO	NO	Grandidier 3/3/2003
6.	Good overview of SiCOM STS reader	NO	NO	Grandidier 3/3/2003
7.	Signal display properly when online monitoring	NO	NO	Grandidier 19/2/2003
8.	File splitting mode working	NO	NO	Grandidier 19/2/2003

Table 3.1: Regression test for the SiCOM system

4 Measurement Campaign at the Deutsche Bahn in Kirchmöser

In this part, we will talk about the measurement campaign that was done at the Deutsche Bahn site and where the SiCOM system was used to record the signals coming from the different sensors.

We explain in detail the organization of the measurement campaign that was done in Kirchmöser. As we were limited in the time because the measurement campaign lasted 1 week, we tried to record as much data as possible in order to have many cases of measurements.

The problem was that at the end of the measurements, we had so many data that we had to find a method to analyse such a big amount of data. For this reason, MATLAB programs such as “SiCOMFourier” or “SiCOMView” that help to visualize and to compare the data were made. Those programs are described in detail in this part.

Of course, those programs are re-usable for other data that will be recorded in the future. For example, another measurement campaign in Kirchmöser is planned in June 2003. During this measurement campaign, we will focus on improving the measurements in order to get more information for our analysis.

4.1 Measurement campaign

The measurement campaign on the Deutsche Bahn site was done in Kirchmöser near Berlin from 20/3/2003 to 26/3/2003. During this campaign, we installed the sensors on and close to the wheelset.

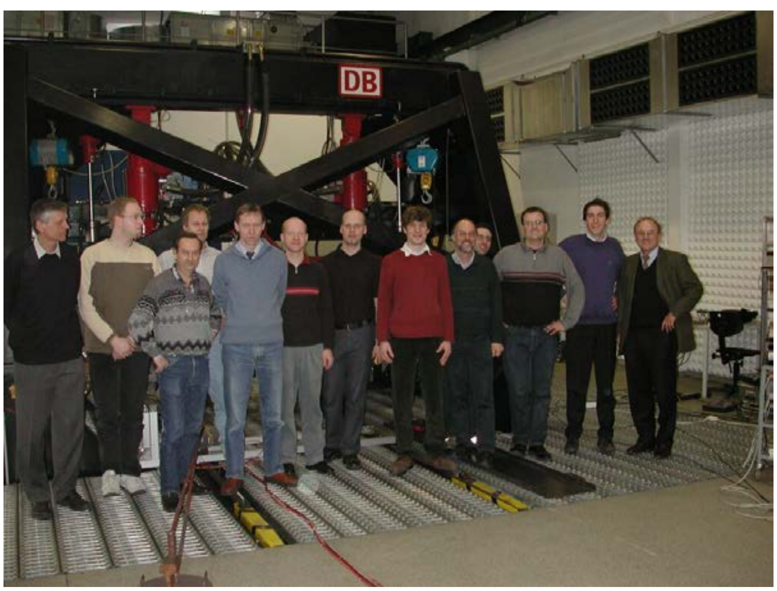


Figure 4.1: The whole team of the measurement campaign in Kirchmöser

A main task was to record the data that were input in the I/Onodes of the SiCOM system.

Figure 4.2: Recording of the data coming from the inputs in the I/Onodes

In this part, we will explain about the organisation of the measurement in Kirchmöser and a way to analyse the recorded data.

4.2 Folder organisation of the measurements in Kirchmöser

The measurements that were recorded in Kirchmöser are stored on the external hard drive H:\ of the SiCOM computer in H:\STS\ as shown on figure 4.3. The results are then sorted by the dates they were recorded and then by their measurement name according to the “Untersuchungsplan Radt/Schiene-Systemprüfstand” of Dr. Lainer, the head of the project Intras 2000+ and responsible from the measurements at the “Deutsche Bahn” (refer to bibliography [Lainer2003]). All the data are stored a second time on the internal hard drive D:\ of the SiCOM computer (D:\STS\Kirchmoeser2003_03\).

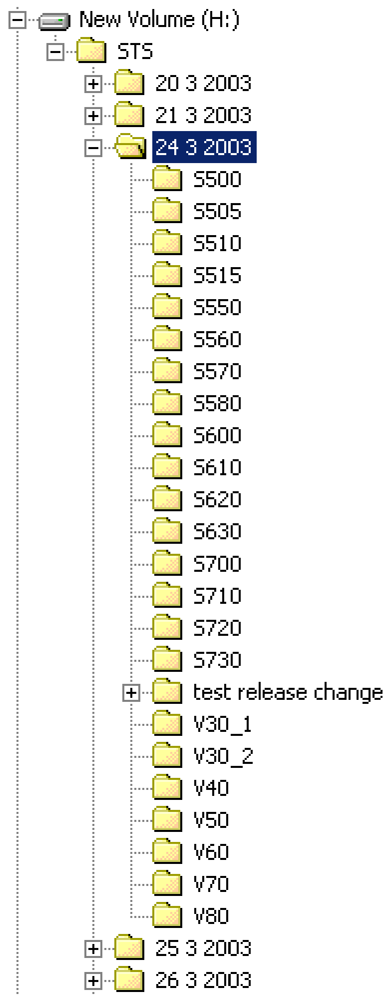


Figure 4.3: Organization of the measurements recorded in Kirchmöser

For better security, the measurements of a same case have been recorded several times.

On figure 4.4, the same case has been recorded during 3s, 10s and 20s. One of these 3 recording can be exported to an ASCII file totally or partially.

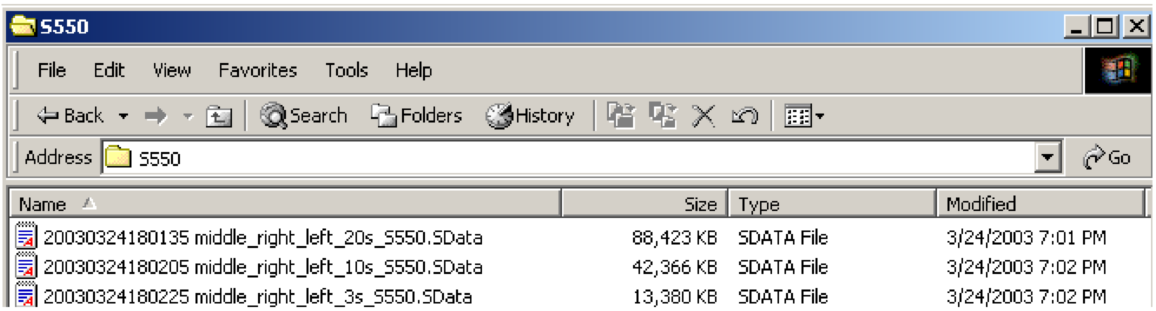


Figure 4.4: Example of some recorded data during the measurements in Kirchmöser

4.3 Correspondance Sensor / I/Onode Channels

This chapter describes the correspondence of sensors and channels of I/Onodes on the 5 measurement days in Kirchmöser.

Measurement day 1: 20/03/2003
Measurement day 2: 21/03/2003
Measurement day 3: 24/03/2003
Measurement day 4: 25/03/2003
Measurement day 5: 26/03/2003

The wheel used can be represented as shown on figure 4.5 with the different holes, slits or flats.

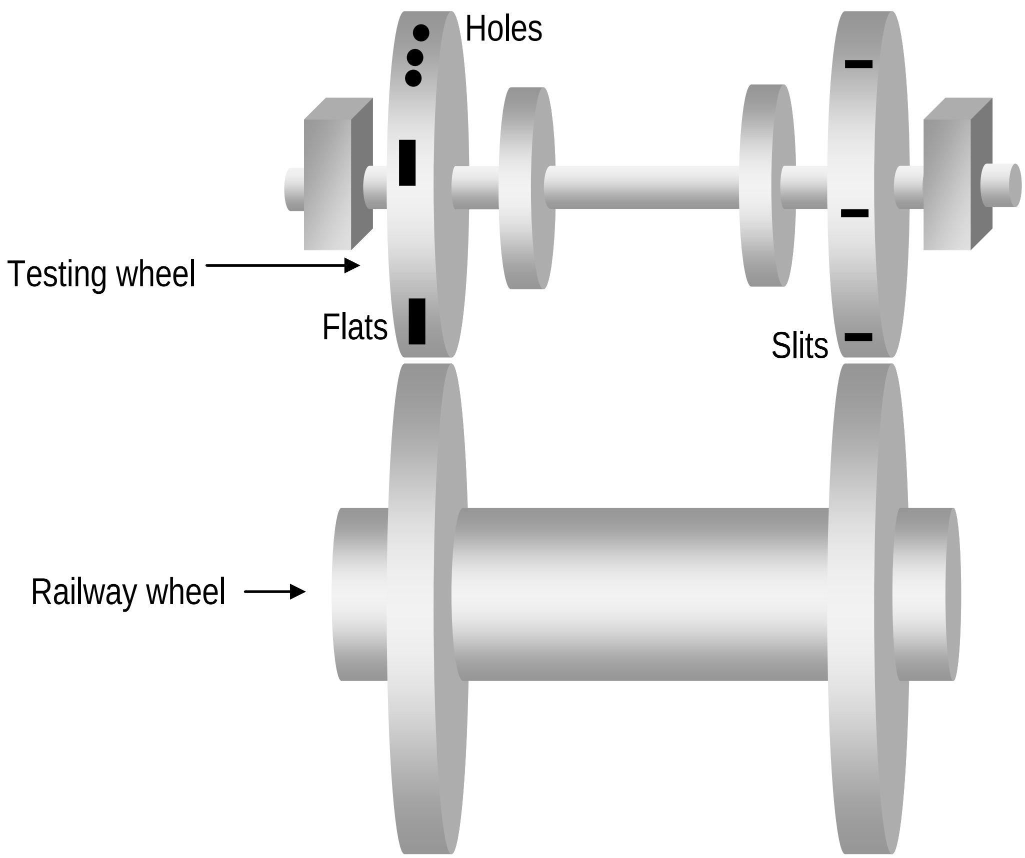


Figure 4.5: Position of the defects on the wheel used during the measurements

Overall, 3 I/Onodes were used and this corresponds to 3 different data files when saved:

M	Middle I/Onode
L	Left I/Onode
R	Right I/Onode

Table 4.1: Correspondence of the I/Onodes

Example for the description in the figures and tables:

RCh6

Corresponds to the **Channel 6** of the **Right I/Onode**

Each channel corresponds to a sensor. In the next figures, we can see to which sensor corresponds which channel with a brief description of the sensor and with the name of the responsible in the team for this sensor.

Example:

MCh4	Eddy current 1	Wünsche – PS9

On the channel 4 of the middle I/Onode, the „Eddy current 1“ sensor is connected.
Mr. Wünsche from department PS9 was responsible for this sensor.

4.3.1 I/Onode connections on measurement day 1 (20/03/2003) measurement day 2 (21/03/2003)

Channel	Sensor Measurements	Responsible
I/Onode 1 – Middle		
MCh1	Trigger 32 imp/Rotation	
MCh2	Rail Wheel trigger 1 imp/Rotation	
MCh3	Trigger 1 impulsion per rotation	
MCh4	Eddy current 1	Wünsche – PS9
MCh5	Eddy current 2	Wünsche – PS9
MCh6	Eddy current 3	Wünsche – PS9
MCh7	Eddy current 4	Wünsche – PS9
MCh8		
I/Onode 2 – Left		
LCh1		
LCh2		
LCh3		
LCh4		
LCh5		
LCh6		
LCh7		
LCh8		
I/Onode 3 – Right		
RCh1	Trigger 32 imp/Rotation	
RCh2	Rail Wheel trigger 1 imp/Rotation	
RCh3	Horizontal vibration Sensor 2	Rieger – PP3
RCh4	Axial vibration Sensor 3	Rieger – PP3
RCh5	Radial vibration Sensor 1	Rieger – PP3
RCh6	Vibration sensor for high frequencies	Jena – PS8
RCh7		
RCh8		

Table 4.2: I/Onode connections on measurement day 1 and 2

*RCh3 (Horizontal vibration Sensor 2) is unplugged on measurement day 1 (20/3/2003).

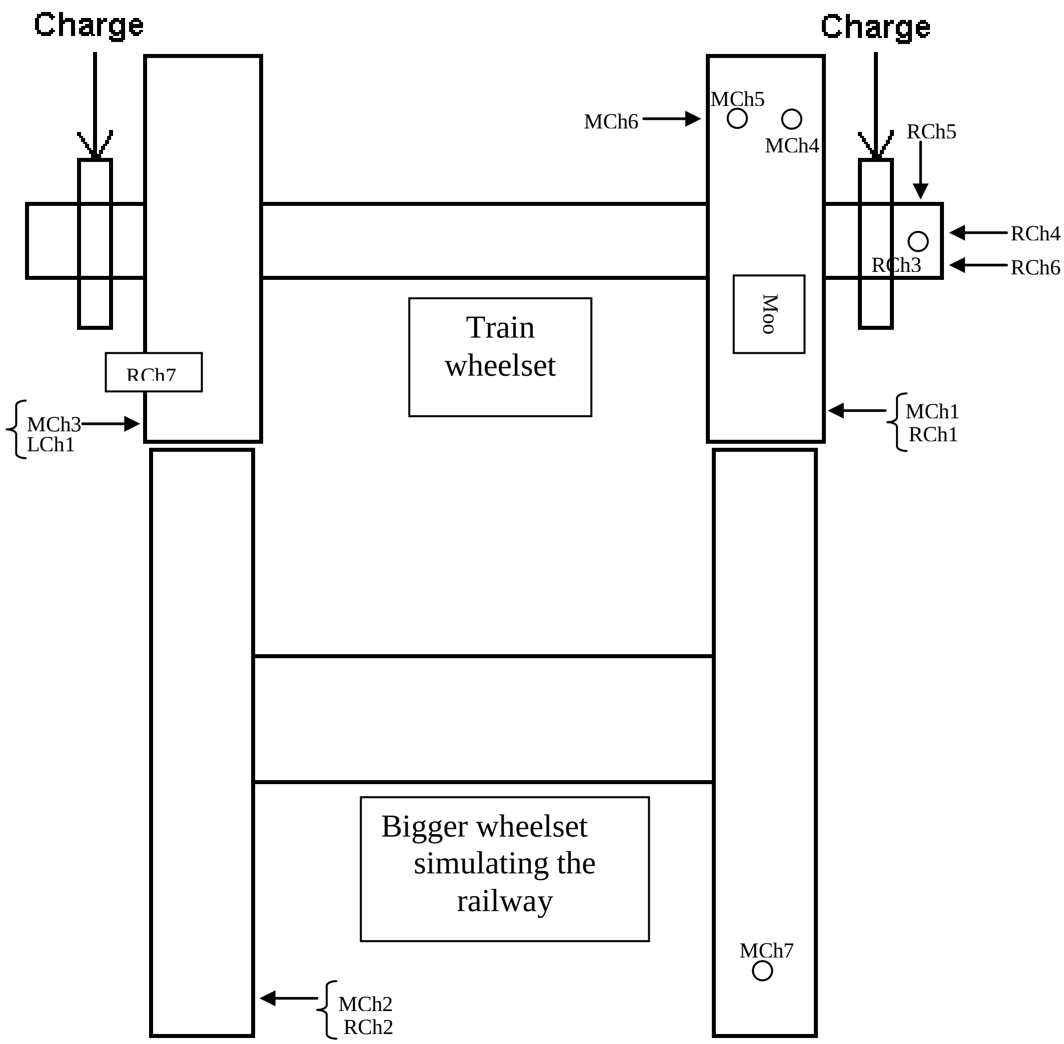


Figure 4.6: I/Onode connections on measurement day 1 and 2

4.3.2 I/Onode connections on measurement day 3 (24/03/2003) measurement day 4 (25/03/2003)

Channel	Sensor Measurements	Responsible
I/Onode 1 – Middle		
MCh1	Trigger 32 imp/Rotation	
MCh2	Rail Wheel trigger 1 imp/Rotation	
MCh3	Trigger 1 impulsion per rotation	
MCh4	Eddy current 1	Wünsche – PS9
MCh5	Eddy current 2	Wünsche – PS9
MCh6	Eddy current 3	Wünsche – PS9
MCh7	Eddy current 4	Wünsche – PS9
MCh8	Kabel 1 Timestamp	Mooshofer – PS5
I/Onode 2 – Left		
LCh1	Kabel 2 Treated trigger 1 imp/rot	Mooshofer – PS5
LCh2	Kabel 3 Burst (excitation of	Mooshofer – PS5
LCh3	sensor)	Mooshofer – PS5
LCh4	Kabel 4 Run (ready to measure)	
LCh5		
LCh6		
LCh7		
LCh8		Mooshofer – PS5
	Kabel 1 Timestamp	
I/Onode 3 – Right		
RCh1	Trigger 32 imp/Rotation	
RCh2	Rail Wheel trigger 1 imp/Rotation	
RCh3	Horizontal vibration Sensor 2	Rieger – PP3
RCh4	Axial vibration Sensor 3	Rieger – PP3
RCh5	Radial vibration Sensor 1	Rieger – PP3
RCh6	Vibration sensor for high	Jena – PS8
RCh7	frequencies	Evers – PS7
RCh8	Radio vibration sensor	Mooshofer – PS5
	Kabel 1 Timestamp	

Table 4.3: I/Onode connections on measurement day 3 and 4

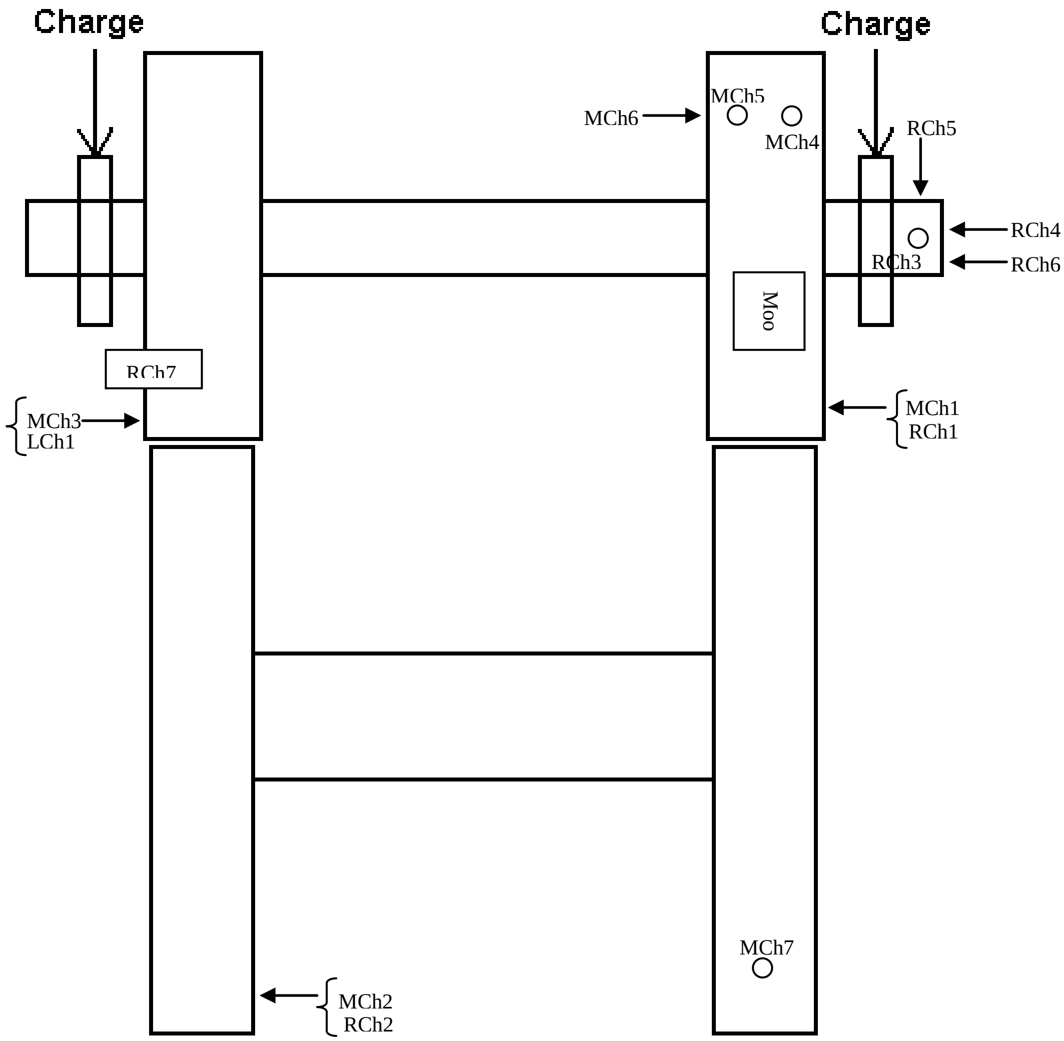


Figure 4.7: I/Onode connections on measurement day 3 and 4

4.3.3 I/Onode connections on measurement day 5 (26/03/2003)

Channel	Sensor Measurements	Responsible
I/Onode 1 – Middle		
MCh1	Trigger 32 imp/Rotation	
MCh2	Rail Wheel trigger 1 imp/Rotation	
MCh3	Trigger 1 impulsion per rotation	
MCh4	Eddy current 1	Wünsche – PS9
MCh5	Eddy current 2	Wünsche – PS9
MCh6	Eddy current 3	Wünsche – PS9
MCh7	Eddy current 4	Wünsche – PS9
MCh8	Kabel 1 Timestamp	Mooshofer – PS5
I/Onode 2 – Left		
LCh1	Kabel 2 Treated trigger 1 imp/rot	Mooshofer – PS5
LCh2	Kabel 3 Burst (excitation of sensor)	Mooshofer – PS5
LCh3		Mooshofer – PS5
LCh4	Kabel 4 Run (ready to measure)	
LCh5		
LCh6		
LCh7		
LCh8	Kabel 1 Timestamp	Mooshofer – PS5
I/Onode 3 – Right		
RCh1	Trigger 32 imp/Rotation	
RCh2	Rail Wheel trigger 1 imp/Rotation	
RCh3	Horizontal vibration Sensor 2	Rieger – PP3
RCh4	Axial vibration Sensor 3	Rieger – PP3
RCh5		
RCh6	Vibration sensor for high frequencies	Jena – PS8
RCh7		
RCh8	Kabel 1 Timestamp	Mooshofer – PS5

Table 4.4: I/Onode connections on measurement day 5

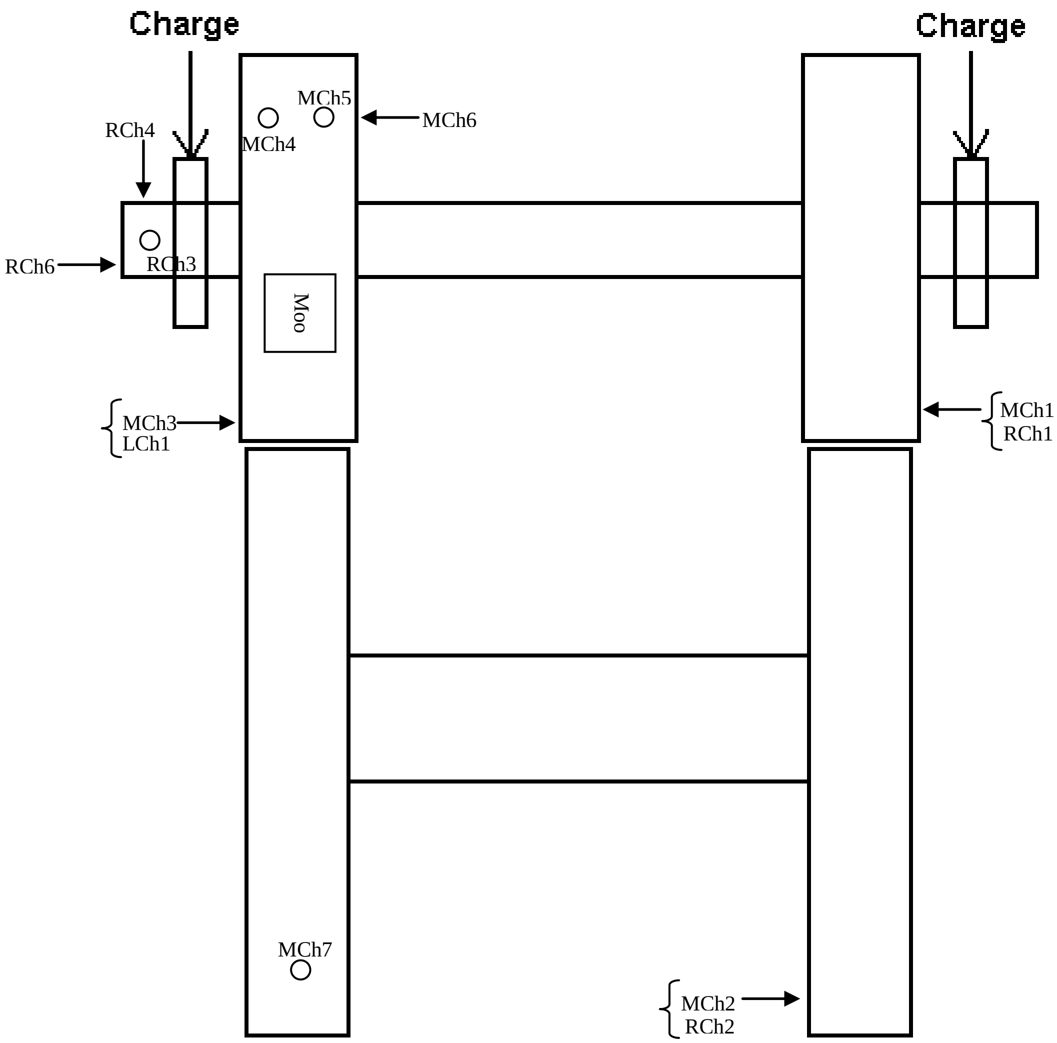


Figure 4.8: I/Onode connections on measurement day 5

4.4 STS Reader

The measured data is stored in a proprietary binary format of the SiCOM-System (*.sdata). STS Reader is a program that can transform these binary files of the SiCOM system into ASCII files.

The next pages explain how to use STS reader.

Transformed to an ASCII file, the data recorded by the SiCOM system can be easily read and analysed e.g. by MATLAB, GNU-Plot or any other program that can plot some data.

The binary data is stored in a format that can only be read by the STS Reader program. For this reason, we transform the data into an ASCII format before using it.

4.4.1 Export a file

We start “STSReader.exe”.
The following screen appears:

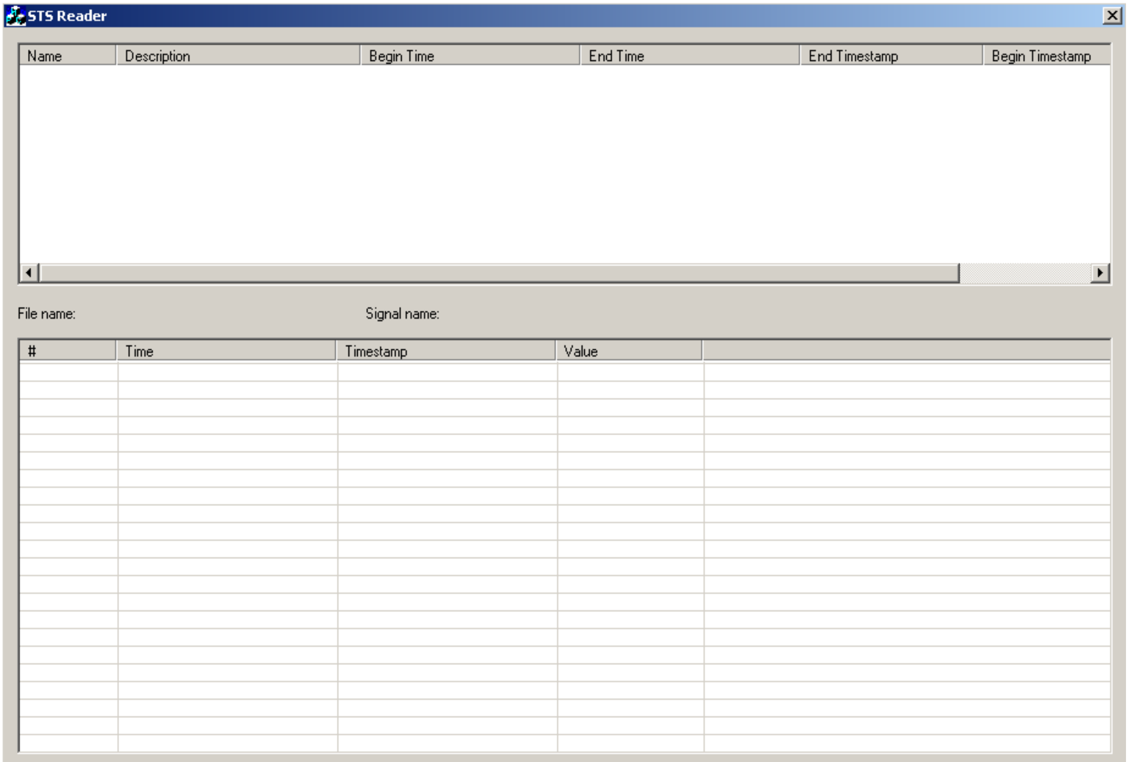
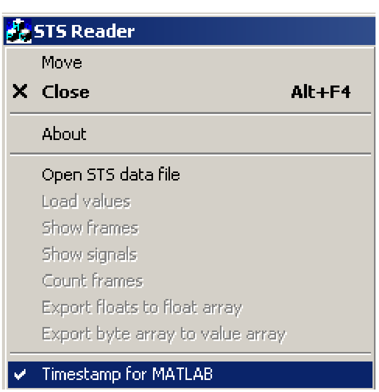


Figure 4.9: STS Reader program to export binary files into ASCII files

To select a binary file that was recorded by the SiCOM system, we click on the STSReader icon on the top left.

We select “Open STS Data File” and open the file corresponding to the wanted measurement.

Note:



If we want to analyse the data with MATLAB, we click on “Timestamp for MATLAB” so that it is enabled.

Figure 4.10: Add the timestamp for MATLAB

When the corresponding STS Data file is opened, we select the wanted I/Onode (Middle, Left or Right)

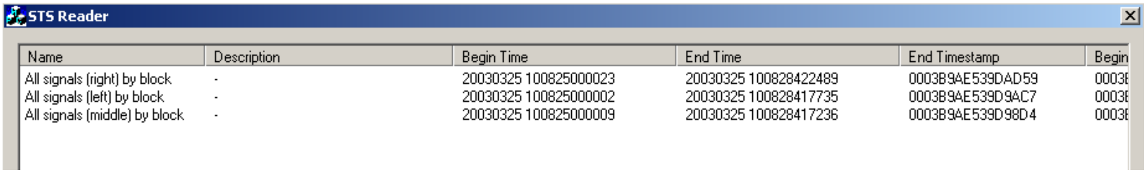


Figure 4.11: Different I/Onodes represented in a binary file

<u>Note:</u>

To know which I/Onode we should select, we refer to chapter 4.3 to know which sensor corresponds to the channel of the I/Onode we have to select

When the wanted I/Onode is selected, we click on the top left icon and select "Export Byte array to value array"

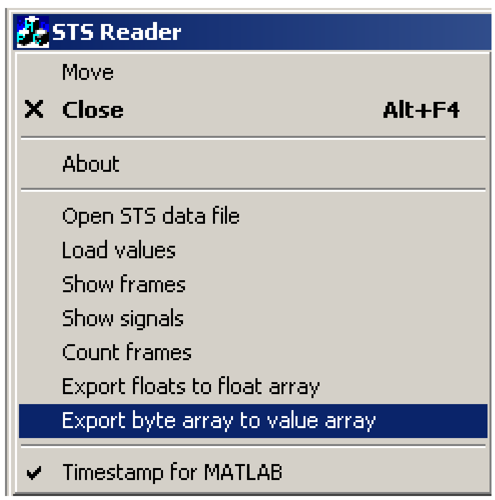


Figure 4.12: Pull down menu of the export function

We select the first row we want and the number of rows. A row is generated every 25µs, this means 40000 rows every seconds (40 kHz).

By default, all rows are selected.

<u>Example:</u> If we want the values of the 3 first seconds, we enter:
First Row ID: 0
Row Count: 120000
Then click on OK

A significant name should be given to the file before clicking on "save".

4.4.2 Representation of the data in files

After the data have been exported, 2 files are created in the same directory of the original binary file:

NameOfFile.txt which contains the data
NameOfFile.txt.log which contains some information about the data

In NameOfFile.txt.log, we can see the minimum and maximum time interval in microseconds. The theorical value is 25µs.

For our data analysis, we should avoid the parts where the time interval is negative as it corresponds to a fixed bug of the SiCOM system.

In NameOfFile.txt, the data is sorted in columns as following:

Col1	Col2	Col3	Col4	Col5	Col6	Col7	Col8	Col9	Col10
Date	Time	Ch1	Ch2	Ch3	Ch4	Ch5	Ch6	Ch7	Ch8

4.5 Analysis of the results with matlab

A good way to analyse the data is by using MATLAB. But as the matrix dimensions are limited to 6,000,000 values, a maximum sample of e.g. 15 seconds of 1 I/Onode can be visualized at once with MATLAB.

A MATLAB program that plots the data stored in the file and calculates a Fourier transformation of it is available with the data files that were recorded in Kirchmöser.

We use MATLAB programs which help to visualize the data recorded with the SiCOM system. With these programs, we can compare the signals recorded simultaneously.

The two main programs to analyse the data are "SiCOMfourier.m" and "SiCOMview.m"

4.5.1 SiCOMFourier

This MATLAB program reads the data exported by STS Reader in an ASCII file and calculates a Fourier transformation of it.

When in MATLAB, select the command "SETPATH" to select the directory where the MATLAB program "SiCOMfourier.m" is. To do this, click on "file" to get the pulldown menu, select "SETPATH" and look for the corresponding directory.

The data are stored in a ".txt" file the following way:

```
20030321 095050000010 +1.29010000E+004 +9.00000000E+000 +1.99000000E+002 +6.98000000E+002 +2.23000000E+002 -2.58800000E+003 +4.00000000E+000 +1.40000000E+001
20030321 095050000035 +1.29580000E+004 -1.60000000E+001 +6.40000000E+001 +5.86000000E+002 +2.99000000E+002 -2.60000000E+003 +2.00000000E+001 +2.00000000E+001
20030321 095050000060 +1.29890000E+004 +1.10000000E+001 +1.73000000E+002 +1.75000000E+002 +2.16000000E+002 -2.60900000E+003 +1.90000000E+001 +1.70000000E+001
20030321 095050000085 +1.30180000E+004 +2.00000000E+001 +8.40000000E+001 +8.30000000E+001 +6.00000000E+001 -2.58500000E+003 +4.00000000E+000 +1.40000000E+001
20030321 095050000110 +1.30030000E+004 -3.40000000E+001 +4.27000000E+002 -1.69000000E+002 -1.00000000E+000 -2.59800000E+003 +9.00000000E+000 +2.20000000E+001
20030321 095050000135 +1.29910000E+004 +1.40000000E+001 +4.87000000E+002 -2.72000000E+002 +4.30000000E+001 -2.62600000E+003 +2.00000000E+001 +1.40000000E+001
20030321 095050000160 +1.30120000E+004 +1.10000000E+001 +3.27000000E+002 -3.88000000E+002 -9.40000000E+001 -2.62000000E+003 +1.80000000E+001 +1.70000000E+001
20030321 095050000185 +1.30070000E+004 -2.50000000E+001 +1.17000000E+002 -3.84000000E+002 -6.90000000E+001 -2.61400000E+003 +7.00000000E+000 +2.00000000E+001
20030321 095050000210 +1.29960000E+004 +3.60000000E+001 +1.85000000E+002 -5.86000000E+002 +1.16000000E+002 -2.65200000E+003 +4.00000000E+000 +9.00000000E+000
20030321 095050000235 +1.30210000E+004 +1.40000000E+001 -3.00000000E+001 -4.25000000E+002 +2.62000000E+002 -2.65400000E+003 +1.60000000E+001 +2.00000000E+001
20030321 095050000260 +1.30140000E+004 -3.00000000E+000 -1.35000000E+002 -3.41000000E+002 +1.44000000E+002 -2.63400000E+003 +2.40000000E+001 +2.50000000E+001
20030321 095050000285 +1.30010000E+004 +4.70000000E+001 +2.50000000E+001 -2.71000000E+002 +2.10000000E+002 -2.65700000E+003 +4.00000000E+000 +1.30000000E+001
20030321 095050000310 +1.30050000E+004 +2.20000000E+001 +1.45000000E+002 -1.00000000E+002 +3.27000000E+002 -2.65200000E+003 +5.00000000E+000 +1.10000000E+001
20030321 095050000335 +1.30180000E+004 -9.00000000E+000 +4.00000000E+001 -3.34000000E+002 +4.10000000E+001 -2.63600000E+003 +2.10000000E+001 +2.70000000E+001
20030321 095050000360 +1.30020000E+004 +4.90000000E+001 +3.38000000E+002 -3.47000000E+002 -1.81000000E+002 -2.64200000E+003 +1.40000000E+001 +1.40000000E+001
20030321 095050000385 +1.29980000E+004 +6.00000000E+000 +5.13000000E+002 -3.75000000E+002 -3.76000000E+002 -2.65900000E+003 +6.00000000E+000 +1.80000000E+001
20030321 095050000410 +1.30140000E+004 -9.00000000E+000 +3.67000000E+002 -3.42000000E+002 -2.86000000E+002 -2.64200000E+003 +1.60000000E+001 +2.00000000E+001
```

Figure 4.13: Data saved in an ASCII format

- The first column corresponds to the date
- The second column corresponds to the time
- The eight other columns correspond to the eight channels of an I/Onode

This file can be easily loaded by MATLAB with the command "load" and the values will be available as a Matrix and named according to the file name, but without ".txt".

The program “SiCOMFourier” uses the following algorithm:

```
% val is the Matrix that contains the data without the first column date
t = val(:,1); % t contains the time column
val = val(:,2:end); % val has now all the informations of the channels

[n,p]=size(val);

y=fft(val); % we perform a Fourier Transformation of the value we have

n=length(y);
y(1,:)=[];
power=abs(y(1:n/2,:)).^2;
nyquist=1/2/mean(diff(t));% mean(diff(t)) is the mean sample time
freq=(1:n/2)/(n/2)*nyquist;

if (number_figures==1) % We plot on 1 figure
   subplot(2,sub_p1,sub_p2),plot(t,val);
   grid;
   xlabel('time');
   ylabel('value');
   title(fname);
   subplot(2,sub_p1,sub_p1+sub_p2),plot(freq,power);
   grid;
   xlabel('cycle');
   title('Fourier Transformation');
else % We plot on several figure
   minval = min(val);
   maxval = max(val);
   meanval = mean(val);
   [maxpow,pow_ind] = max(power);
   minpow = min(power);
   meanpow = mean(power);
   for i=1:p
      figure(i)
      subplot(2,sub_p1,sub_p2),plot(t,val(:,i));
      grid;
      hold on
      plot([t(1),t(end)],[minval(i),minval(i)],'r')
      plot([t(1),t(end)],[maxval(i),maxval(i)],'r')
      plot([t(1),t(end)],[meanval(i),meanval(i)],'g')
      xlabel('time');
      ylabel(['channel ',int2str(columns_look_at(i)-2)]);
      title(fname);
      subplot(2,sub_p1,sub_p1+sub_p2),plot(freq/trigger(i),power(:,i));
      grid;
      hold on
      plot([freq(pow_ind(i)),freq(pow_ind(i))]/trigger(i),[minpow(i),maxpow(i)],'r')

text(freq(pow_ind(i))/trigger(i),meanpow(i),int2str(round(freq(pow_ind(i))/trigger(i))))
      xlabel('cycle');
      ylabel(['channel ',int2str(columns_look_at(i)-2)]);
      title('Fourier Transformation');
   end
end
```

Figure 4.14: Part of the algorithm used for the “SiCOMFourier” program

For better understanding, we just show the part of the program that performs a Fourier transformation and plots the signal and the Fourier transformation.

The Fourier transformation (4.2) is done with the FFT function and is performed by the equation:

$$X(k+1) = \sum_{n=0}^{N-1} x(n+1) W_N^{kn} \qquad (4.2)$$

where:

$$W_N = e^{-j(2\pi/N)} \qquad (4.3)$$

To use the program, we type in Matlab:

SiCOMfourier([X, Y …], N)

where N is the number of graphs we want. X and Y are the number of channels (see section 4.4.2).
After pressing "Enter", a dialog box appears and we have to select the corresponding file where the channels we want to visualize are.

<u>Example 1:</u>
To Visualise Ch3 and Ch6 on 2 different graphs, we type:
SiCOMfourier([3,6],2)
The result we obtain is shown on figure 4.15.

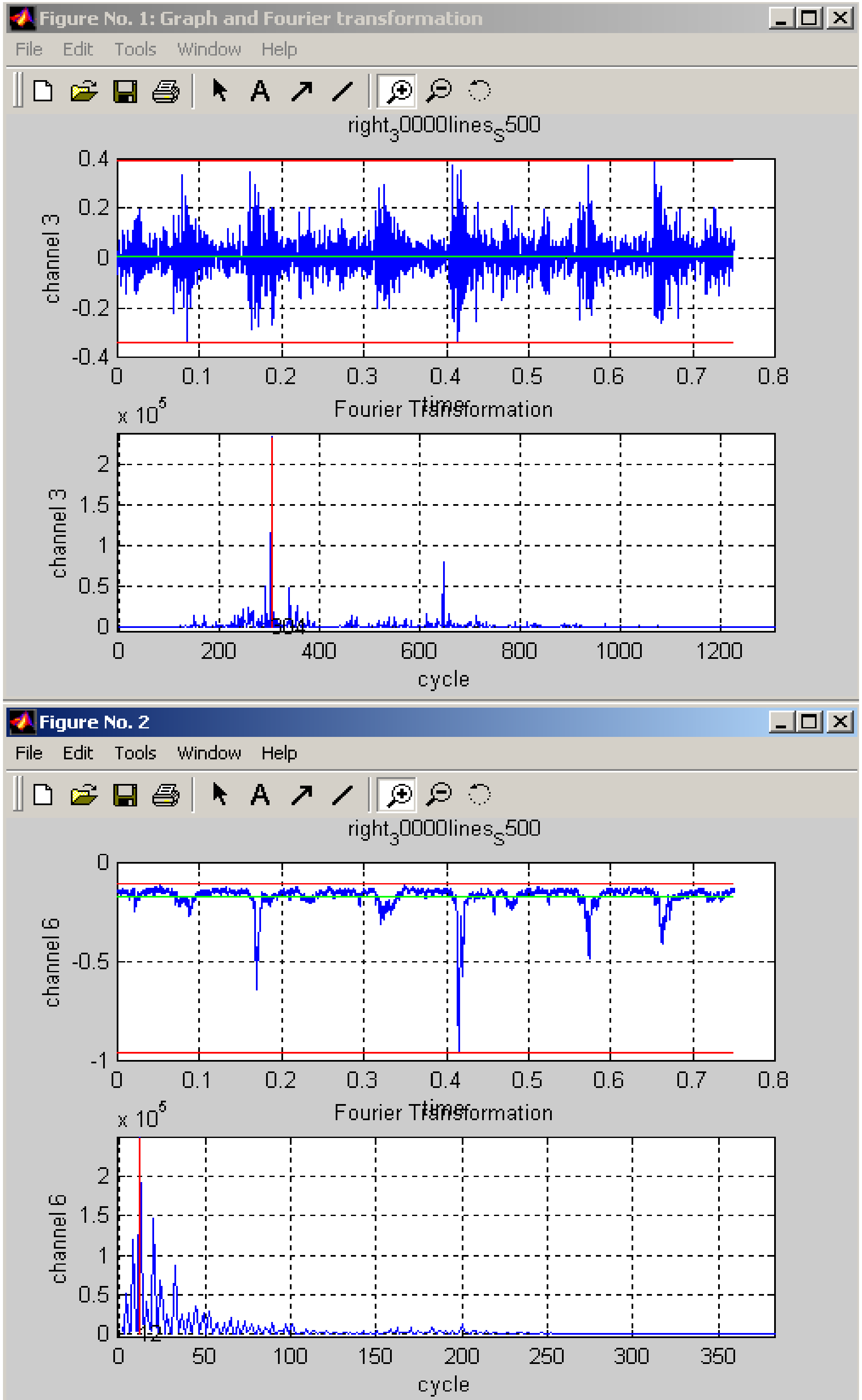


Figure 4.15: Result of "SiCOMFourier([3,6],2)"

The 2 selected channels are on 2 different windows. On each window, we can see on top the plot of the channel. The abscise is the time and the ordinate is the amplitude of the signal. The 2 red lines correspond to the maximum and minimum value of the plot and the green line correspond to the mean value. On the bottom, we can see the Fourier transformation of the plot. The red line corresponds to the maximum value of the Fourier transformation.

Example 2:
To Visualise Ch3 and Ch6 on the same graphs, type:
SiCOMfourier([3,6],1)
The result we obtain is shown on figure 4.16.

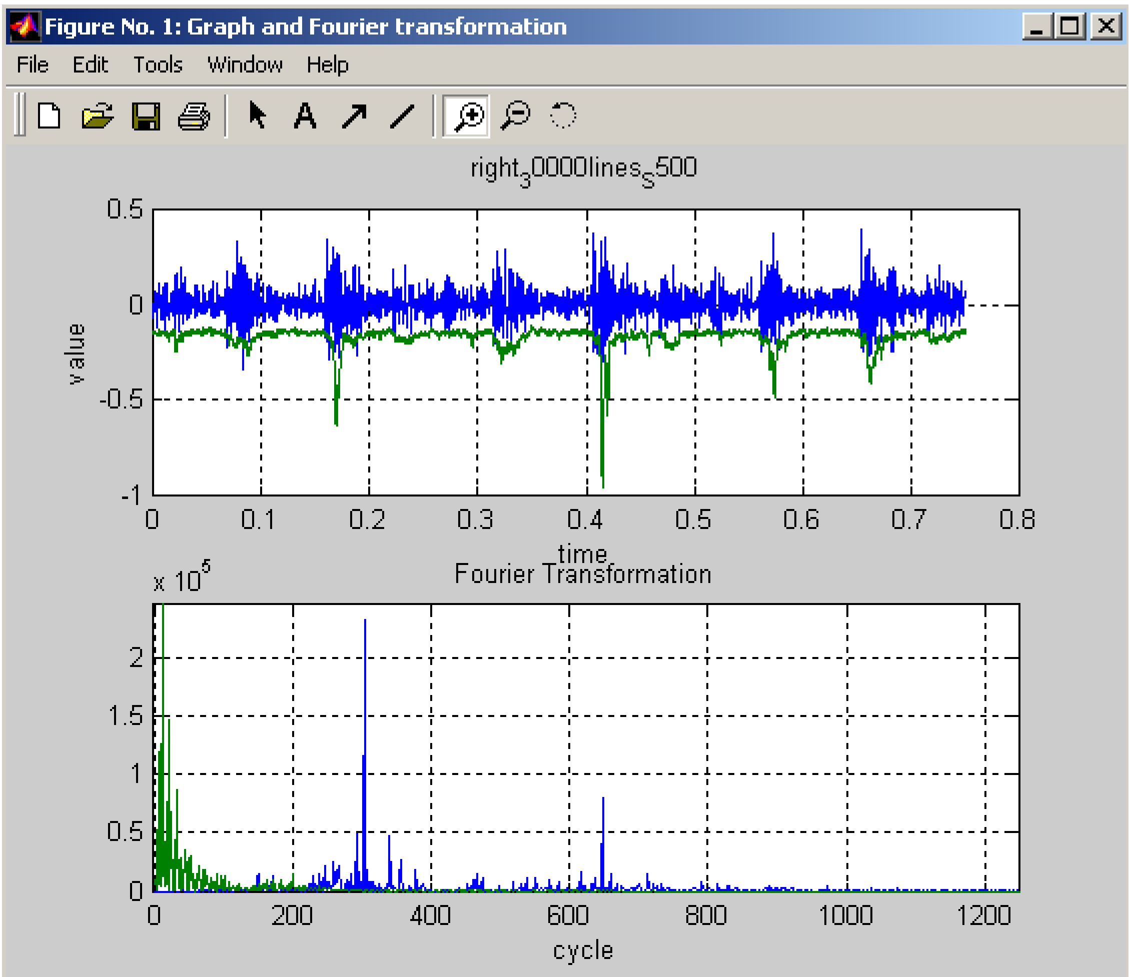


Figure 4.16: Result of "SiCOMFourier([3,6],1)"

The result is the same as before but the 2 selected channels are on the same graph. On top, the 2 plots in 2 different colors. On the bottom, the 2 Fourier transformations in 2 different colors.

4.5.2 SiCOMView

This MATLAB program enables to visualize several channels at the same time. It is useful to compare the different channels.

In the same way as the preceding program, when we are in MATLAB, we have to select the command "SETPATH" to select the directory where the MATLAB program "SiCOMview.m" is.

This program is similar to the plot signal part of "SiCOMFourier" so we do not write the algorithm another time.

To use this program, type in MATLAB:

SiCOMview([X, Y …])

Where x and y are the channels we want to see.

Example:

To Visualise Ch3, Ch4 and Ch6, we type:
SiCOMview([3,4,6])
The result we obtain is shown on figure 4.17.

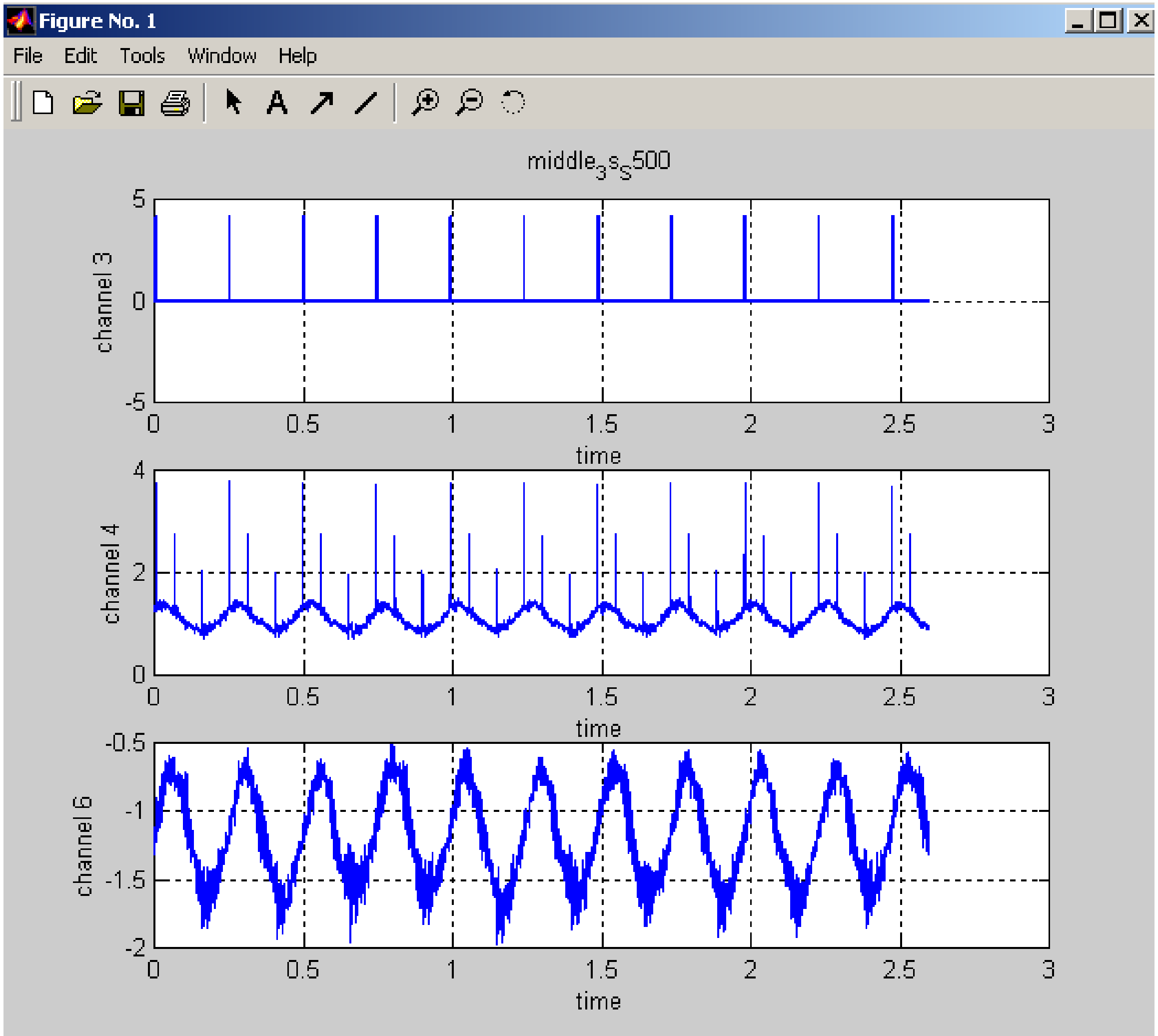


Figure 4.17: Result of "SiCOMView([3,4,6])"

The 3 selected channels are on the same window but on 3 different graphs. It is then easy to compare the plots as they are plotted from the top to the bottom.

4.6 Split Files

When recording a program with the SiCOM system, it can happen that the file is so large that its exported version to an ASCII file is impossible to be read by MATLAB or in another way. A solution for this problem is to export a smaller amount of lines when using STS Reader. Another program “Cygwin” can be used to split an ASCII file into several ASCII files with a selected number of lines.

This program has to be installed under Windows and is used with Unix commands.

After having executed the “Cygwin” program, the directory where the file we want to split has to be selected. To do this, we use the command “CD” as we would do under a Unix system.

When we are in the right directory, the command to split a file is:

Split.exe –l numberoflines nameoffile.txt nameofnewfile

Then, we have to add “.txt” to the created files. An automated command to do it is:

For I in nameofnewfile*; do mv $I $I.txt; done

For example, to split a file named “S020.txt” of 30 lines into 2 files of 15 lines each which will be named “S020splitaa.txt” and “S020splitab.txt”, we type the 2 following commands after having selected the directory in which S020.txt is:

Split.exe –l 15 S020.txt S020split
For I in S020split*; do mv $I $I.txt; done

At the end, we will have 3 files as shown on figure 4.18.

"S020.txt"

```
20030324 180415000024 +1.31370000E+004 -5.00000000E+000 +7.00000000E+001 -7.23000000E+002 +5.09000000E+002 -4.52000000E+002 -9.70000000E+001 +2.20000000E+001
20030324 180415000049 +1.31270000E+004 +2.30000000E+001 +1.30000000E+002 -6.85000000E+002 +3.14000000E+002 -4.34000000E+002 -1.50000000E+002 -2.00000000E+000
20030324 180415000074 +1.31480000E+004 -2.90000000E+001 +1.62000000E+002 -6.02000000E+002 +1.93000000E+002 -4.47000000E+002 -1.69000000E+002 +1.50000000E+001
20030324 180415000099 +1.31370000E+004 +5.90000000E+001 +1.60000000E+001 -3.73000000E+002 +3.92000000E+002 -4.41000000E+002 -1.68000000E+002 +2.70000000E+001
20030324 180415000125 +1.31310000E+004 -2.00000000E+000 -6.70000000E+001 -4.90000000E+002 +4.13000000E+002 -4.42000000E+002 -1.45000000E+002 -4.00000000E+000
20030324 180415000150 +1.31560000E+004 +1.00000000E+001 -1.32000000E+002 -2.87000000E+002 +2.75000000E+002 -4.56000000E+002 -2.14000000E+002 +1.40000000E+001
20030324 180415000174 +1.31360000E+004 +3.10000000E+001 -1.20000000E+002 -5.60000000E+001 +1.05000000E+002 -4.54000000E+002 -2.44000000E+002 +3.50000000E+001
20030324 180415000199 +1.31330000E+004 -5.60000000E+001 -9.70000000E+001 -4.30000000E+001 -1.47000000E+002 -4.71000000E+002 -2.47000000E+002 -8.00000000E+000
20030324 180415000224 +1.31470000E+004 +8.00000000E+000 -6.30000000E+001 -2.80000000E+001 -2.02000000E+002 -4.91000000E+002 -2.07000000E+002 -6.00000000E+000
20030324 180415000249 +1.31240000E+004 +9.00000000E+000 -1.00000000E+000 -1.79000000E+002 -1.80000000E+002 -4.84000000E+002 -1.51000000E+002 +3.50000000E+001
20030324 180415000274 +1.31300000E+004 -1.10000000E+001 +1.60000000E+001 -2.66000000E+002 -5.60000000E+001 -4.98000000E+002 -1.72000000E+002 +1.80000000E+001
20030324 180415000299 +1.31440000E+004 +3.10000000E+001 +3.80000000E+001 -7.20000000E+001 +3.80000000E+001 -5.11000000E+002 -8.80000000E+001 +2.00000000E+000
20030324 180415000324 +1.31250000E+004 -2.60000000E+001 -2.10000000E+002 -1.59000000E+002 -2.30000000E+002 -5.04000000E+002 -1.01000000E+002 +4.30000000E+001
20030324 180415000349 +1.31380000E+004 +1.60000000E+001 -3.34000000E+002 -6.80000000E+001 -3.88000000E+002 -5.22000000E+002 -1.10000000E+002 +3.80000000E+001
20030324 180415000375 +1.31380000E+004 +1.20000000E+001 -3.96000000E+002 +1.15000000E+002 -3.65000000E+002 -5.31000000E+002 -9.70000000E+001 -7.00000000E+000
20030324 180415000400 +1.31260000E+004 -1.80000000E+001 -4.32000000E+002 +6.80000000E+001 -2.72000000E+002 -5.16000000E+002 -7.40000000E+001 +1.60000000E+001
20030324 180415000425 +1.31410000E+004 +3.80000000E+001 -5.03000000E+002 +2.07000000E+002 -2.50000000E+002 -5.30000000E+002 -3.20000000E+001 +4.10000000E+001
20030324 180415000450 +1.31380000E+004 -3.60000000E+001 -3.62000000E+002 +1.99000000E+002 -3.12000000E+002 -5.31000000E+002 -3.80000000E+001 -1.80000000E+001
20030324 180415000474 +1.31310000E+004 +0.00000000E+000 -4.40000000E+002 +1.07000000E+002 -3.59000000E+002 -5.21000000E+002 -6.00000000E+001 +1.00000000E+000
20030324 180415000499 +1.31490000E+004 +1.70000000E+001 -3.54000000E+002 +2.50000000E+001 -5.06000000E+002 -5.37000000E+002 -2.20000000E+001 +3.00000000E+001
20030324 180415000524 +1.31290000E+004 -1.80000000E+001 -4.20000000E+002 -6.30000000E+001 -7.24000000E+002 -5.21000000E+002 +1.80000000E+001 +0.00000000E+000
20030324 180415000550 +1.31310000E+004 +6.00000000E+001 -4.64000000E+002 -2.04000000E+002 -5.64000000E+002 -5.23000000E+002 +2.80000000E+001 +2.00000000E+000
20030324 180415000575 +1.31370000E+004 -1.60000000E+001 -3.37000000E+002 -1.57000000E+002 -6.10000000E+002 -5.34000000E+002 +3.00000000E+001 +2.90000000E+001
20030324 180415000600 +1.31210000E+004 -1.70000000E+001 -4.90000000E+002 -4.00000000E+001 -6.51000000E+002 -5.12000000E+002 -7.10000000E+001 +2.10000000E+001
20030324 180415000625 +1.31320000E+004 +1.70000000E+001 -5.16000000E+002 -4.00000000E+000 -5.81000000E+002 -5.22000000E+002 -1.09000000E+002 +8.00000000E+000
20030324 180415000650 +1.31430000E+004 -1.70000000E+001 -4.24000000E+002 +9.30000000E+001 -5.14000000E+002 -5.23000000E+002 -1.30000000E+002 +3.80000000E+001
20030324 180415000674 +1.31240000E+004 +5.50000000E+001 -3.79000000E+002 +2.57000000E+002 -5.11000000E+002 -5.01000000E+002 -1.65000000E+002 +2.90000000E+001
20030324 180415000699 +1.31350000E+004 +5.00000000E+000 -3.29000000E+002 +3.99000000E+002 -3.97000000E+002 -5.18000000E+002 -5.60000000E+001 -1.00000000E+000
20030324 180415000724 +1.31360000E+004 -1.50000000E+001 -2.72000000E+002 +3.78000000E+002 -5.42000000E+002 -5.17000000E+002 -1.20000000E+001 +3.80000000E+001
20030324 180415000749 +1.31360000E+004 +1.20000000E+001 -2.54000000E+002 +4.49000000E+002 -4.65000000E+002 -4.94000000E+002 +9.20000000E+001 +2.40000000E+001
```

S020splitaa.txt

```
20030324 180415000024 +1.31370000E+004 -5.00000000E+000 +7.00000000E+001 -7.23000000E+002 +5.09000000E+002 -4.52000000E+002 -9.70000000E+001 +2.20000000E+001
20030324 180415000049 +1.31270000E+004 +2.30000000E+001 +1.30000000E+002 -6.85000000E+002 +3.14000000E+002 -4.34000000E+002 -1.50000000E+002 -2.00000000E+000
20030324 180415000074 +1.31480000E+004 -2.90000000E+001 +1.62000000E+002 -6.02000000E+002 +1.93000000E+002 -4.47000000E+002 -1.69000000E+002 +1.50000000E+001
20030324 180415000099 +1.31370000E+004 +5.90000000E+001 +1.60000000E+001 -3.73000000E+002 +3.92000000E+002 -4.41000000E+002 -1.68000000E+002 +2.70000000E+001
20030324 180415000125 +1.31310000E+004 -2.00000000E+000 -6.70000000E+001 -4.90000000E+002 +4.13000000E+002 -4.42000000E+002 -1.45000000E+002 -4.00000000E+000
20030324 180415000150 +1.31560000E+004 +1.00000000E+001 -1.32000000E+002 -2.87000000E+002 +2.75000000E+002 -4.56000000E+002 -2.14000000E+002 +1.40000000E+001
20030324 180415000174 +1.31360000E+004 +3.10000000E+001 -1.20000000E+002 -5.60000000E+001 +1.05000000E+002 -4.54000000E+002 -2.44000000E+002 +3.50000000E+001
20030324 180415000199 +1.31330000E+004 -5.60000000E+001 -9.70000000E+001 -4.30000000E+001 -1.47000000E+002 -4.71000000E+002 -2.47000000E+002 -8.00000000E+000
20030324 180415000224 +1.31470000E+004 +8.00000000E+000 -6.30000000E+001 -2.80000000E+001 -2.02000000E+002 -4.91000000E+002 -2.07000000E+002 -6.00000000E+000
20030324 180415000249 +1.31240000E+004 +9.00000000E+000 -1.00000000E+000 -1.79000000E+002 -1.80000000E+002 -4.84000000E+002 -1.51000000E+002 +3.50000000E+001
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20030324 180415000299 +1.31440000E+004 +3.10000000E+001 +3.80000000E+001 -7.20000000E+001 +3.80000000E+001 -5.11000000E+002 -8.80000000E+001 +2.00000000E+000
20030324 180415000324 +1.31250000E+004 -2.60000000E+001 -2.10000000E+002 -1.59000000E+002 -2.30000000E+002 -5.04000000E+002 -1.01000000E+002 +4.30000000E+001
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20030324 180415000375 +1.31380000E+004 +1.20000000E+001 -3.96000000E+002 +1.15000000E+002 -3.65000000E+002 -5.31000000E+002 -9.70000000E+001 -7.00000000E+000
```

S020splitab.txt

```
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20030324 180415000425 +1.31410000E+004 +3.80000000E+001 -5.03000000E+002 +2.07000000E+002 -2.50000000E+002 -5.30000000E+002 -3.20000000E+001 +4.10000000E+001
20030324 180415000450 +1.31380000E+004 -3.60000000E+001 -3.62000000E+002 +1.99000000E+002 -3.12000000E+002 -5.31000000E+002 -3.80000000E+001 -1.80000000E+001
20030324 180415000474 +1.31310000E+004 +0.00000000E+000 -4.40000000E+002 +1.07000000E+002 -3.59000000E+002 -5.21000000E+002 -6.00000000E+001 +1.00000000E+000
20030324 180415000499 +1.31490000E+004 +1.70000000E+001 -3.54000000E+002 +2.50000000E+001 -5.06000000E+002 -5.37000000E+002 -2.20000000E+001 +3.00000000E+001
20030324 180415000524 +1.31290000E+004 -1.80000000E+001 -4.20000000E+002 -6.30000000E+001 -7.24000000E+002 -5.21000000E+002 +1.80000000E+001 +0.00000000E+000
20030324 180415000550 +1.31310000E+004 +6.00000000E+001 -4.64000000E+002 -2.04000000E+002 -5.64000000E+002 -5.23000000E+002 +2.80000000E+001 +2.00000000E+000
20030324 180415000575 +1.31370000E+004 -1.60000000E+001 -3.37000000E+002 -1.57000000E+002 -6.10000000E+002 -5.34000000E+002 +3.00000000E+001 +2.90000000E+001
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20030324 180415000674 +1.31240000E+004 +5.50000000E+001 -3.79000000E+002 +2.57000000E+002 -5.11000000E+002 -5.01000000E+002 -1.65000000E+002 +2.90000000E+001
20030324 180415000699 +1.31350000E+004 +5.00000000E+000 -3.29000000E+002 +3.99000000E+002 -3.97000000E+002 -5.18000000E+002 -5.60000000E+001 -1.00000000E+000
20030324 180415000724 +1.31360000E+004 -1.50000000E+001 -2.72000000E+002 +3.78000000E+002 -5.42000000E+002 -5.17000000E+002 -1.20000000E+001 +3.80000000E+001
20030324 180415000749 +1.31360000E+004 +1.20000000E+001 -2.54000000E+002 +4.49000000E+002 -4.65000000E+002 -4.94000000E+002 +9.20000000E+001 +2.40000000E+001
```

Figure 4.18: Example of a file and 2 split files

In a case of larger files, MATLAB would be able to read independently the 2 split files when it was unable to read the file containing all the data.

5 Analysis of the Measurements

As the measurements made during the measurement campaign in Kirchmöser are the most detailed we have, we mostly use them for our analysis. Moreover, we got some measurements from Siemens Austria on a real train. For this reason, we also analyse those measurements in order to compare them with the measurements we made in Kirchmöser.

In this part, we will first focus on a general comparison of the different signals that were recorded in Kirchmöser. We will then find some characteristic frequencies. Finally, we will analyse the results from a real train we got from Siemens Austria and look for characteristic frequencies. For this, we will use the "SiCOMFourier" and "SiCOMView" programs that we described in part 4 of this report.

5.1 Aim of the Analysis and signal processing

5.1.1 Aim of the analysis

The aim of the analysis is to determine which sensor can detect what kind of defects and which sensor is the most sensitive one for a special failure on the wheel. We already know that some sensors are difficult to use on a real train because they are not so robust. Nevertheless, we keep and analyse the signals of all the sensors in order to compare the signals. The idea is that the defects detected by one sensor can help to detect the same defects by another sensor.

Each member of the team is doing a specific analysis for his sensor. In the department IC4, our task is to do a global analysis of all the signals from the sensors.

5.1.2 Signal processing

The SiCOM system is able to record signals with a sample rate up to 40 kHz. According to the Shannon's theorem signals, the form of sinus waves can be detected until a wave frequency of 20 kHz. Vibrations of higher frequencies cannot be detected appropriately.

In spite of this theoretical limit, it is possible to get information about vibrations of higher frequencies by means of analog signal processing.

The original acceleration signal can be transformed to an envelope curve as described in figure 5.1.

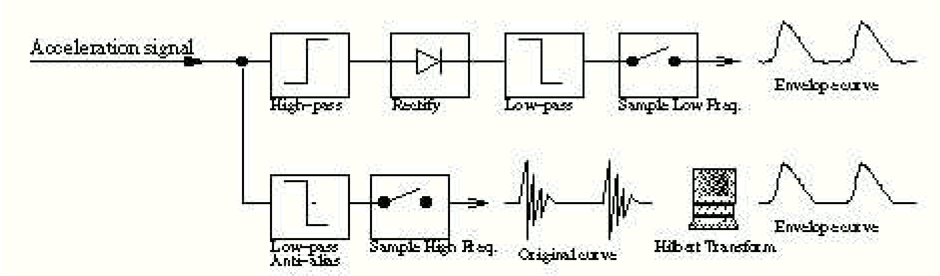

Figure 5.1: Two ways to calculate the envelope curve of a signal

The first method of figure 5.1 uses a high-pass filter, a rectifier and a low-pass filter. This signal processing can be performed by analog filters. The envelope curve of lower frequencies can be recorded by a digital measurement system with a low sample rate. This approach was applied for the recording of signals from the vibration sensor focused on higher frequencies.

The second method of figure 5.1 to get the envelope curve of a digital signal is to carry out a Hilbert transformation of the raw signals.

The Hilbert transformation (5.1) is a finite impulse response filter. It delays in 90 degrees in phase the sample time signal and gives an envelope of the raw signal. Its equation is:

$$\mathrm{H}[x(t)] = \int_{-\infty}^{+\infty} \frac{x(u)}{u-t} du \qquad (5.1)$$

5.2 Comparison of the signals

5.2.1 Method of analysis

For this analysis, we consider the data we got during the measurement campaign in Kirchmöser. For this reason, we can refer to chapter 4.3 to understand the position of the mentioned signals.

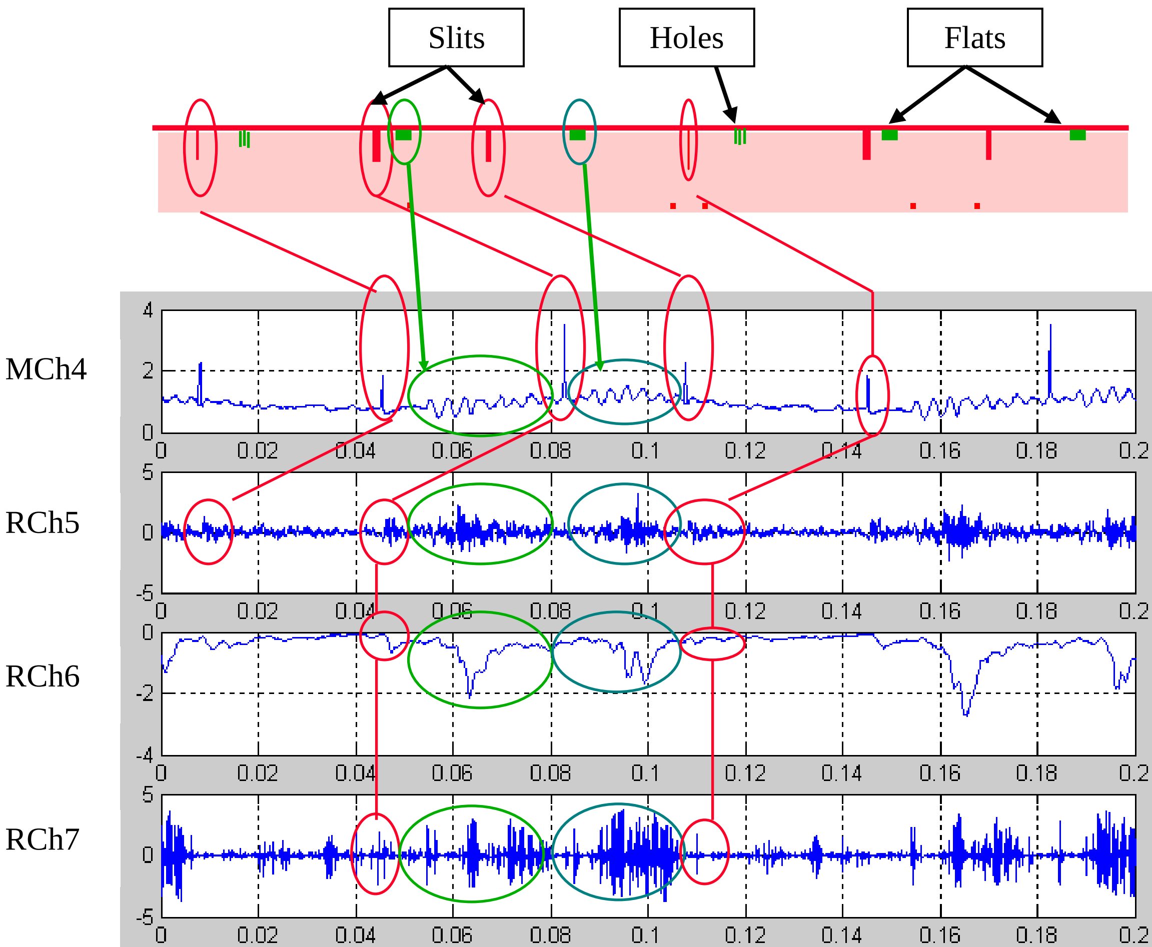

Figure 5.2: Detection of the defects by the different sensor

On the figure 5.2, we can compare the different defects detected by the sensors. In this case, the wheels are running at 100 km/h with a 6T load. This is a sample time of 0.2s. On the top are the position of the defects. In red, we see the slits of the right wheel of the wheelset and in green, the flats of the left wheel. Then we see in the following order from up to down the signals coming from the sensors:

- Eddy current 1 — MCh4, measured on the left side
- Radial vibration sensor — RCh5, measured on the left side
- Vibration sensor high frequencies — RCh6, measured on the left side
- Radio vibration sensor on the wheel — RCh7, measured on the right wheel

The signals of the vibration sensor high frequency are processed to an envelope curve. The first method of the two described on figure 5.1 is applied.

For better comparison, the signals of the radial vibration sensor could be transformed to an envelope curve as well, either by the Hilbert transformation or by high-pass filter rectifiers and low-pass filters.

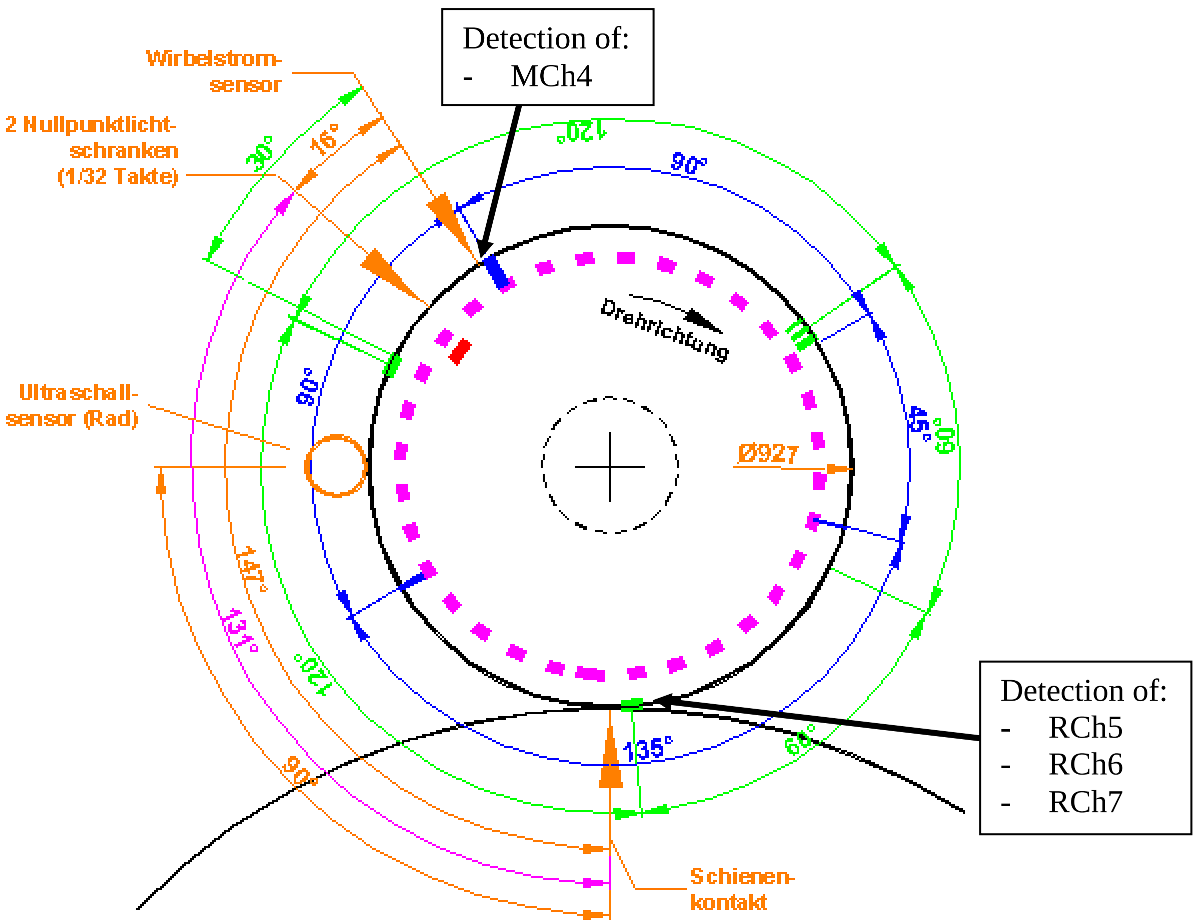

Figure 5.3: Position of the different sensors on the wheel

On figure 5.2, we can see that there is a delay between the viewing of the same defect with 2 different sensors. The reason of this delay can be understood by analysing figure 5.3. The figure 5.3 shows the position of the sensors on the wheel. As the sensors are in different positions on the wheel, there need to be a partial rotation of the wheel so the defects can be detected by two different sensors.

As we can see on figure 5.2, the flats and the slits an be detected in a different way by the different sensors depending on their type and their position on the wheelset.

As the radio vibration sensor on the wheel has some effects that perturb a good recording of the signal, we focus on the 4 following signals that are the most relevant for our comparison analysis.

- 1 impulsion trigger MCh3, measured on the left side
- Eddy current 1 MCh4, measured on the left side
- Radial vibration sensor RCh5, measured on the left side
- Vibration sensor high frequencies RCh6, measured on the left side

A comparison for different cases with a load of 6 tons and 10 tons at different speeds is carried out for:

- The cracks of the damaged wheel which is in contact with the track
- The flats of the damaged wheel which is in contact with the track
- The holes of the damaged wheel which is in contact with the track

As we do an analysis on many figures, it is difficult to show all of them in this document. Therefore we will show an example (figure 5.4 and 5.5) and explain to which values we refer to in the following table. On the abscise axis is the time and on the ordonate axis is the amplitude of the signals in different cases of sensors. Ratios are also calculated with values of measurements done with a good wheelset or reference wheelset that does not have any major defects.

Refering to the figure 5.4 and 5.5, the notable values are:

$A_{mean,f}$ = mean amplitude of the wheel with failures
$A_{max,g}$ = maximum amplitude of good wheel
$A_{max,f}$ = maximum amplitude of wheels with failures

To determine the quality of the detection of the defects, the following ratios are used:

$$R_f = \frac{A_{\max,f}}{A_{mean,f}} \quad (5.2)$$

and

$$R_{g,f} = \frac{A_{\max,f}}{A_{\max,g}} \quad (5.3)$$

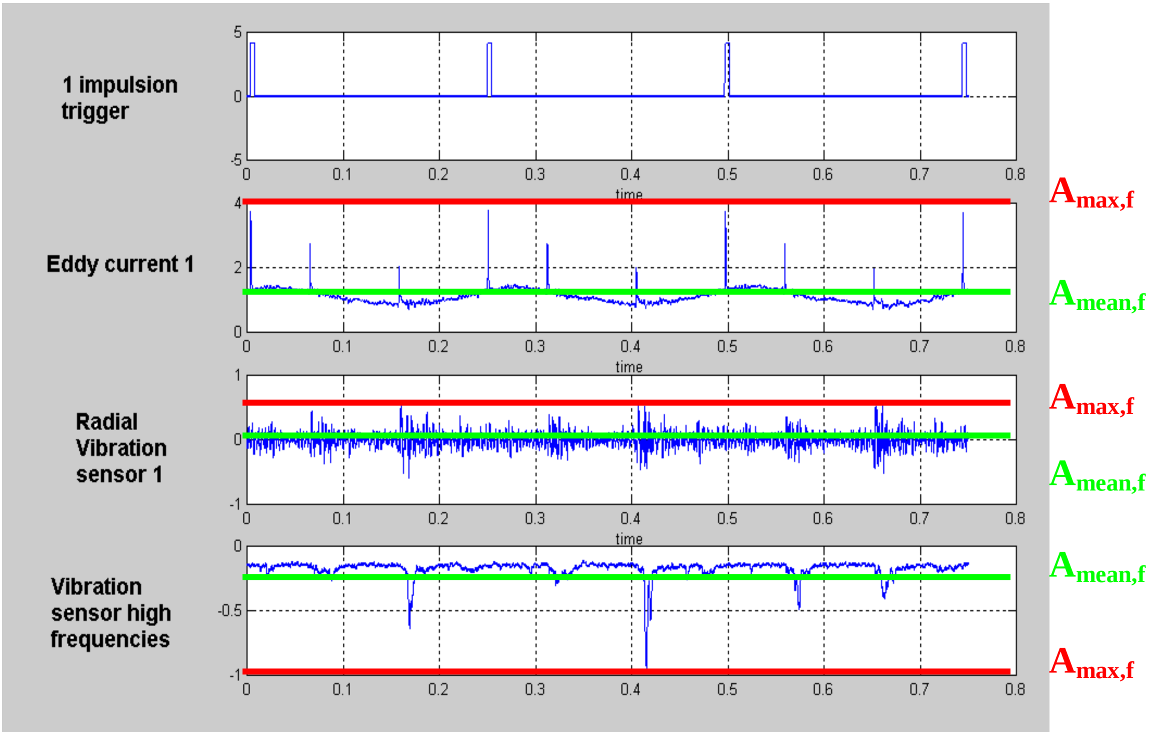

Figure 5.4: Damaged wheel on cracks

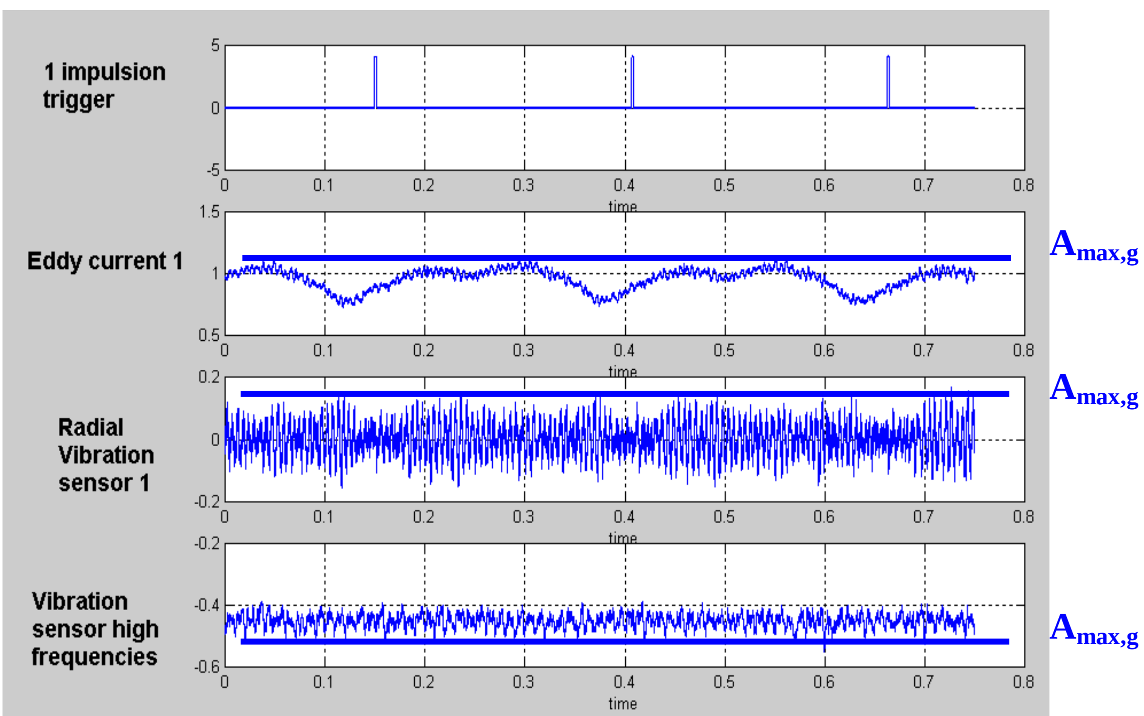

Figure 5.5: Good wheel or reference wheel

5.2.2 Analysis of the general results

After analysing several figures and making the ratios R_f (5.2) and $R_{g,f}$ (5.3), we get the following table that helps us to say if the defects can be well or not detected:

Slits	10 km/h	20 km/h	40 km/h	60 km/h	100 km/h	220 km/h
Vibration 1, 6t	+	+	+ (10;4,29)		0	0 (10;2,5)
Vibration 1, 10t						
Vibration high freq, 6t	0 ?	+	0 (1,52;1,32)		- ?	0 (1,83;1,47)
Vibration high freq 10t						
Eddy current 1, 6t	++	++	++ (4,32;3,45)		++	++ (12,33;3,36)
Eddy current 1, 10t						

Flat spots	10 km/h	20 km/h	40 km/h	60 km/h	100 km/h	220 km/h
Vibration 1, 6t			++ (10;10)	++*		+ (10;5)
Vibration 1, 10t			+			
Vibration high freq, 6t			+ (7,61;5,13)	+*		0 ? (0,29;0,23)
Vibration high freq 10t			+			
Eddy current 1, 6t			++ (1,48;1,18)			-
Eddy current 1, 10t			+			

Holes on the surface	10 km/h	20 km/h	40 km/h	60 km/h	100 km/h	220 km/h
Vibration 1, 6t			-	0*		--
Vibration 1, 10t						
Vibration high freq, 6t			-	0*		--
Vibration high freq 10t						
Eddy current 1, 6t			--	0*		--
Eddy current 1, 10t						

Table 5.1: General result table of the measurements done in Kirchmöser

*:good view of the plot

Sign	Meaning
++	failure very good to separate
+	good detection
o	failure can be detected
-	no clear failure detection
--	failure not detected

Table 5.2: Coding for the estimation of the detection of the failures

After the estimation, we indicate on the table 5.1 the ratios (5.2) and (5.3)when available, e.g.: “+ (10;4,29)”

On the table 5.2, there is the coding for the estimation of the detection of the failures.

As described on this table, the best signal to detect most of the defects comes from the eddy current sensor and this is without considering the speed. Nevertheless, there is a tendency that the failures are less and less visible when the speed is increasing. The vibration sensor’s results are quite positive as even if the failure aren’t always very easily separated, we can still detect them and the Eddy current signal helps us to detect them by comparison. The vibration sensor for high frequencies gives more or less the same results as the vibration sensor as it is treated for high frequencies.

At 60 km/h, we can see that the holes on the surface are quite well detected but we have to consider that this plot at 60 km/h was very well recorded and the conditions of analysis were almost perfect.

To sum up this analysis, we can say that the amount of data is so large that we have to select what we analyse and give a global estimation. We will go further in details in a next campaign of measurements, as we will measure more specific defects.

5.3 Resonance frequency

The goal of the current analysis is to find the resonance frequencies of the complete wheelset used in Kirchmöser. These frequencies are characteristic frequencies of the wheelset. This means that they are independent from the speed of the wheelset. Also, they should not be too influenced by the failures which are on the wheel. With this analysis, we will also be able to discover some specific frequencies of the system.

We will first describe the method of our analysis. Then we will describe some significant frequencies and we will analyse the frequencies we noticed.

5.3.1 Method of analysis

We do our analysis on a whole acceleration of the wheelset from 10 to 220 km/h when the load is 6T and 10T. The signals we analyse come from a vibration sensor placed on the fixed part of the wheel, from a vibration sensor placed on one of the wheels or from an eddy current sensor. We analyse data of an acceleration from 0 to 220 km/h. This means that the time period of each revolution differs. However, we are interested in a constant time interval to build the mean of a Fourier transformation at different speeds. To have a difference between the smallest and the highest speed less than factor 5, we separate our analysis into 2 parts. One is from 10 to 50 km/h and the other one is from 50 to 220 km/h. With this separation, we can also differentiate some frequencies that are excited only at high or low speed.

5.3.1.1 From 10 to 50 km/h

The following procedure is done:
- Measure the time “a” of a complete revolution at 10 km/h.
- Divide the time of the acceleration from 10 to 50 km/h into equal parts of length a.
- Do a Fourier transform of each part of length “a”
- Calculate the average of all the Fourier transforms

5.3.1.2 From 50 to 220 km/h

The following procedure is done:
- Measure the time “a” of a complete revolution at 50 km/h.
- Proceed the same way as from 10 to 50 km/h until 220 km/h.

With this method, we always have a Fourier transform of at least 1 revolution and never more than 5 revolutions.

5.3.1.3 Different cases

The analysis was carried out in different cases:
- The wheel does not have any defaults “Good wheel”.
- The track is in contact with the “cracks” of the wheel.
- The track is in contact with the “flats” of the wheel.

5.3.2 Significant frequencies

5.3.2.1 14300 Hz

At low speed with a 6T load, we can notice a major frequency of 14300 Hz. At highest speed, it is still there but the amplitude of its representation on the Fourier transform is divided by 30. With a load of 10T, the amplitude of the Fourier transformation is divided by 2 at low speed and is slightly higher at high speed.

This frequency of about 14300 Hz is present in all cases with different amplitudes. The amplitude is generally decreasing when the speed and the load increase.

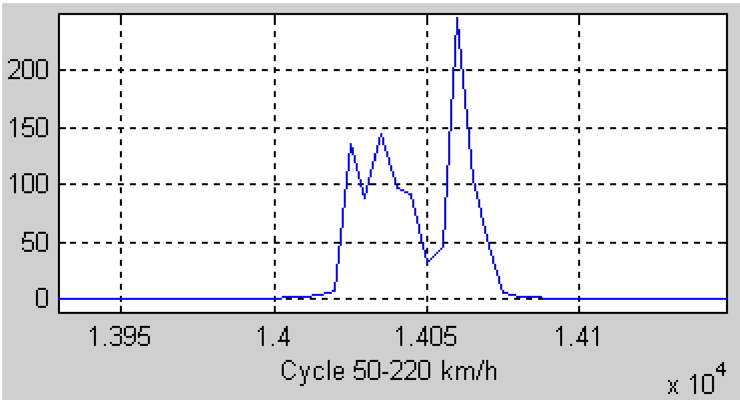

Figure 5.6: High speed, good wheel, vibration sensor

5.3.2.2 2200 Hz

This frequency appears on the good wheel at low speed and is divided by about 20 at high speed. When the wheel is on the cracks, it is not relevant at low speed, but it has a Fourier transform amplitude of 1000 at high speed. It is very well represented at high speed when the wheel is on the flats and the load is 10 T as the amplitude is 100000.

This frequency of 2200 Hz is also represented in all cases but is seems to be more important when there are more defects and when the speed and load are increasing.

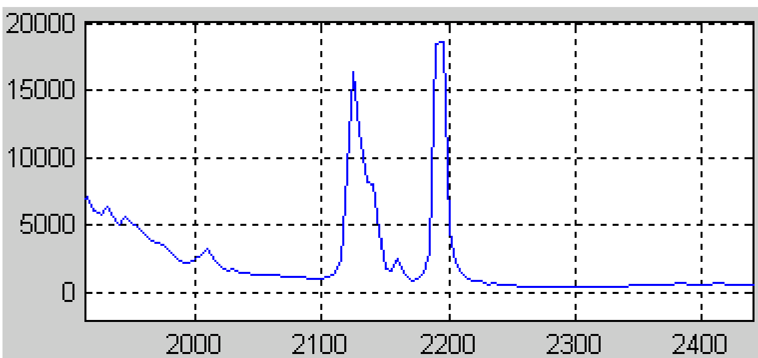

Figure 5.7: High speed, wheel on flats, vibration sensor

5.3.2.3 4800 Hz

This frequency appears significantly on the good wheel and it is decreasing of a factor of 12 between the low and the high speed. It also appears when the wheel is on slits or flats but it is less significant as it is hidden by other frequencies.

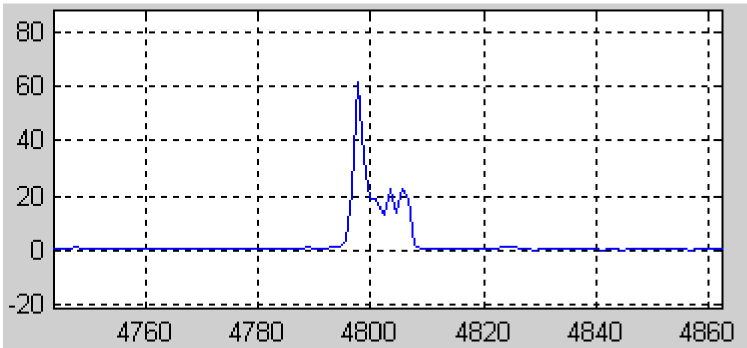

Figure 5.8: Low speed, good wheel, vibration sensor

5.3.2.4 145 Hz

This frequency is very significant when the wheel has some defects. At low speed with a load of 6T, the amplitude of the Fourier transform is 1500000 and it is decreasing of a factor of 20 at high speed. Moreover, on the good wheel, this frequency is almost invisible but still has a Fourier transformation of an amplitude of a few units.

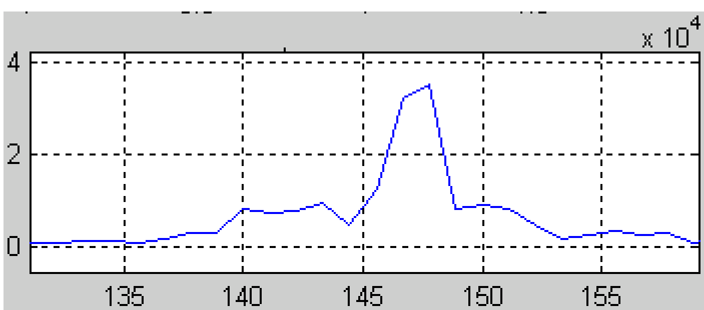

Figure 5.9: Low speed, wheel on cracks, vibration sensor

5.3.2.4 3300 Hz

This frequency is not visible at low speed and on the good wheel. Nevertheless, it appears very significantly when the wheel has defects and at high speed. It seems to decrease when the load is increasing.

5.3.3 Analysis of the frequencies

For a better consideration of the results, the table 5.3 was used in order to analyse the significant frequencies.

With the previous description, we can notice some significant frequencies. The most significant one is 2200 Hz as it appears anytime. It means it is completely independent from the defects and the speed even if the Fourier transform is more or less amplified with those factors. This independence can lead us to say that 2200 Hz is the resonance frequency of the whole wheelset.

The frequency of 3300 Hz appears with defects at high speed. This means it is excited by the defaults when the speed gets higher. As this frequency is independent from the type of defaults, we can say that it is characteristic to the wheelset and the defects only help to excite it.

The same conclusion can be made for 145 Hz but at low speed. This frequency does not appear on the good wheel but is also independent from the type of defects. This means it is also proper to the wheelset and some defects help to excite it.

The frequency of 4800 Hz appears on the good wheel and is hidden by other frequencies when the wheel is on defects. As it is not very significant but still there in all cases, we could say that this frequency is a resonance frequency of one of the component of the wheelset: It could be the resonance frequency of the bearing or of the wheel.

These are the most significant frequencies of the wheelset independently from the speed and the kind of defaults. There are other frequencies that are significant but only with a certain kind of defects.

Another frequency appears on the Fourier transform every 50 Hz. However, it is not considered it as it is most likely that this frequency comes from the power supply.

5.3.4 Conclusion for the characteristic frequencies

We could see with this analysis that some frequencies are independent from the speed and the defects of the wheelset. Even if they are independent, those frequencies are more or less excited depending on the speed, the load or the defects of the wheelset. From this analysis, we could formulate a strong hypothesis on the resonance frequencies of the whole system and some other frequencies that are probably the frequencies of single components of the wheelset.

On our next measurement campaign in Kirchmöser planned in June 2003, we could eventually perform some banging tests on the different components of the wheelset independently and mounted and compare the results with our current analysis to get a better estimation of the resonance frequency of the whole system and the components.

5.4 Measurements on a real train given by Siemens Austria

The goal of this analysis is to detect some specific frequencies in order to eventually find some similarities to the measurements that were made in Kirchmöser.

The data we have come from measurements that were made on the wheels of a real train about 2 years ago. As those measurements come from a real train they have the advantage to be very realistic. The effects of a real railway also occur in the signals

5.4.1 Information about the measurements

The measurements come from a vibration sensor. They were done on 3 kinds of bogies:

- One where the bearings of the wheel have an eccentricity.
- One where the wheels have some defects.
- One where the wheel is polygonal.

This means we have 4 vibrations sensors per bogie and we get 4 sets of data per kind of bogie as there are 4 wheels per bogie.

5.4.1.1 Velocity of the wagon with the eccentric bearings

The trigger of the eccentric bearing case is unavailable so we do not have any information of the speed of the wagon in this case.

5.4.1.2 Velocity of the wagon where the wheels have defects

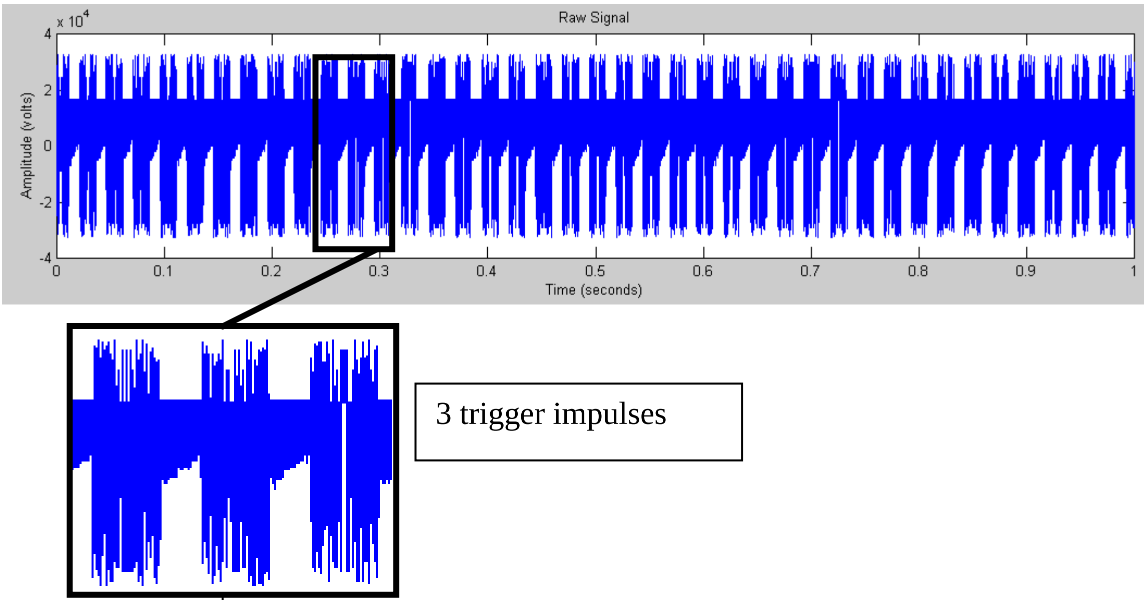

Figure 5.10: Trigger of the wheel with defects case

On the figure 5.8 of the trigger, we can see 40 impulsions per seconds. As the diameter of the wheel is d = 0.9215m, the distance done in one rotation is:

distance = π*0.9215 = 2.895 m

So the distance D done in 1s is: D=2.895*40=115.8m

This mean the speed is: v = D/t = 115.8 m/s or 416.8 km/h

As this speed cannot be so fast, we assume that there is two trigger impulsion per rotation which means the real speed of the train is:

$$V = 416.8 / 2 = 208.4 \text{ km/h} \quad (5.3)$$

This estimation is a bit less than the theoretical speed which is 280 km/h.

5.4.1.3 Velocity of the wagon with the polygonal wheels

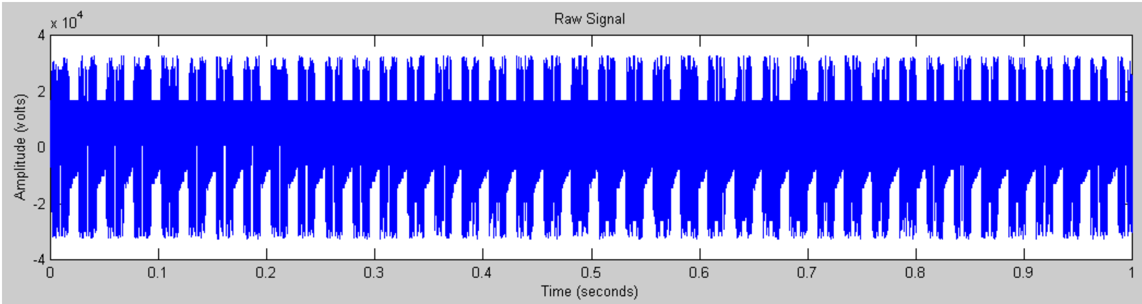

Figure 5.11: Trigger of the polygonal wheels case

In this case, we also have 40 trigger impulsions per seconds. This means the speed is similar as in the previous case and more or less equal to 208.4 km/h.

5.4.2 Notable frequencies in different cases

5.4.2.1 Wagon with the eccentric bearings

The notable frequencies of the wagon with the eccentric bearing are represented on the following figures:

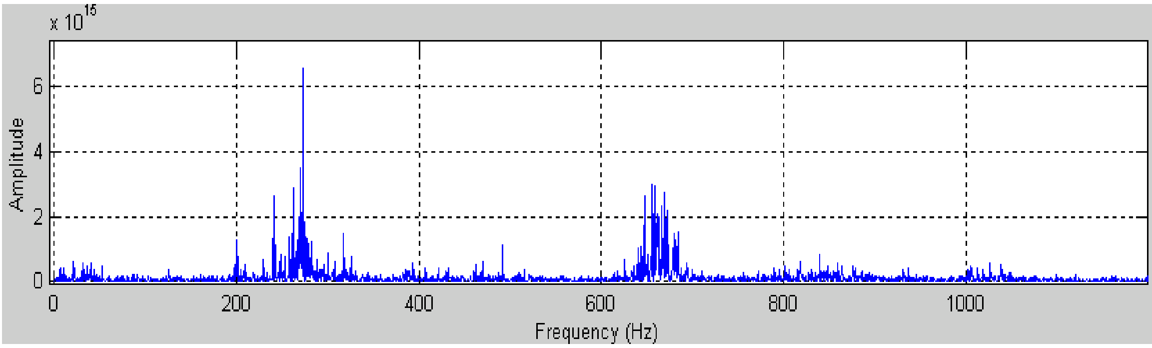

Figure 5.12: Fourier transformation in the lower frequencies for the case VL (front left wheel) of the eccentric bearing

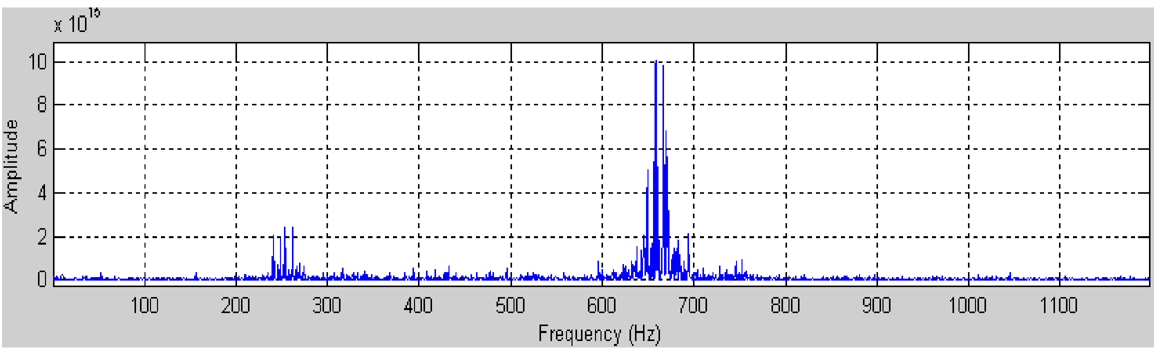

Figure 5.13: Fourier transformation in the lower frequencies for the case VR (front right wheel) of the eccentric bearing

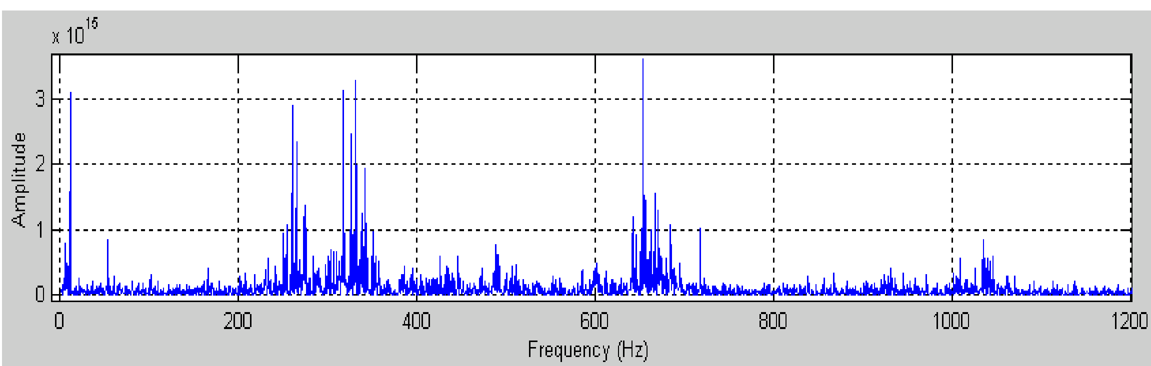

Figure 5.14: Fourier transformation in the lower frequencies for the case HL (back left wheel) of the eccentric bearing

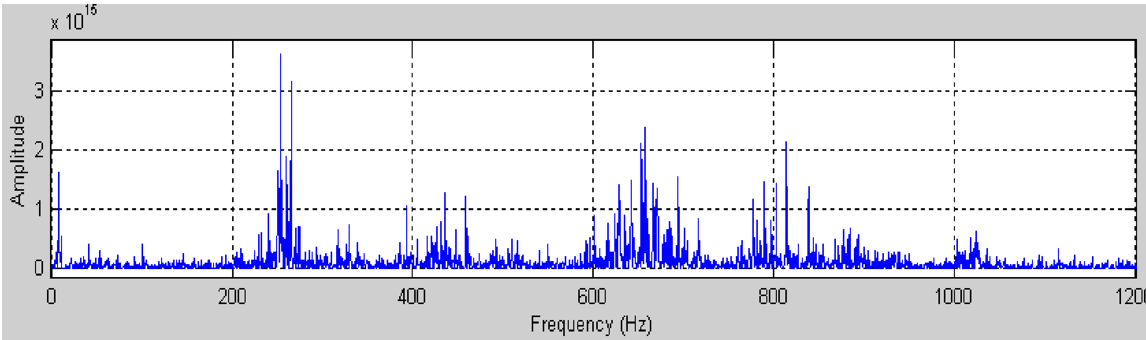

Figure 5.15: Fourier transformation in the lower frequencies for the case HR (back right wheel) of the eccentric bearing

We can represent the preceding results and the ones represented on the table with the notable values of the frequency on the wagon as following:

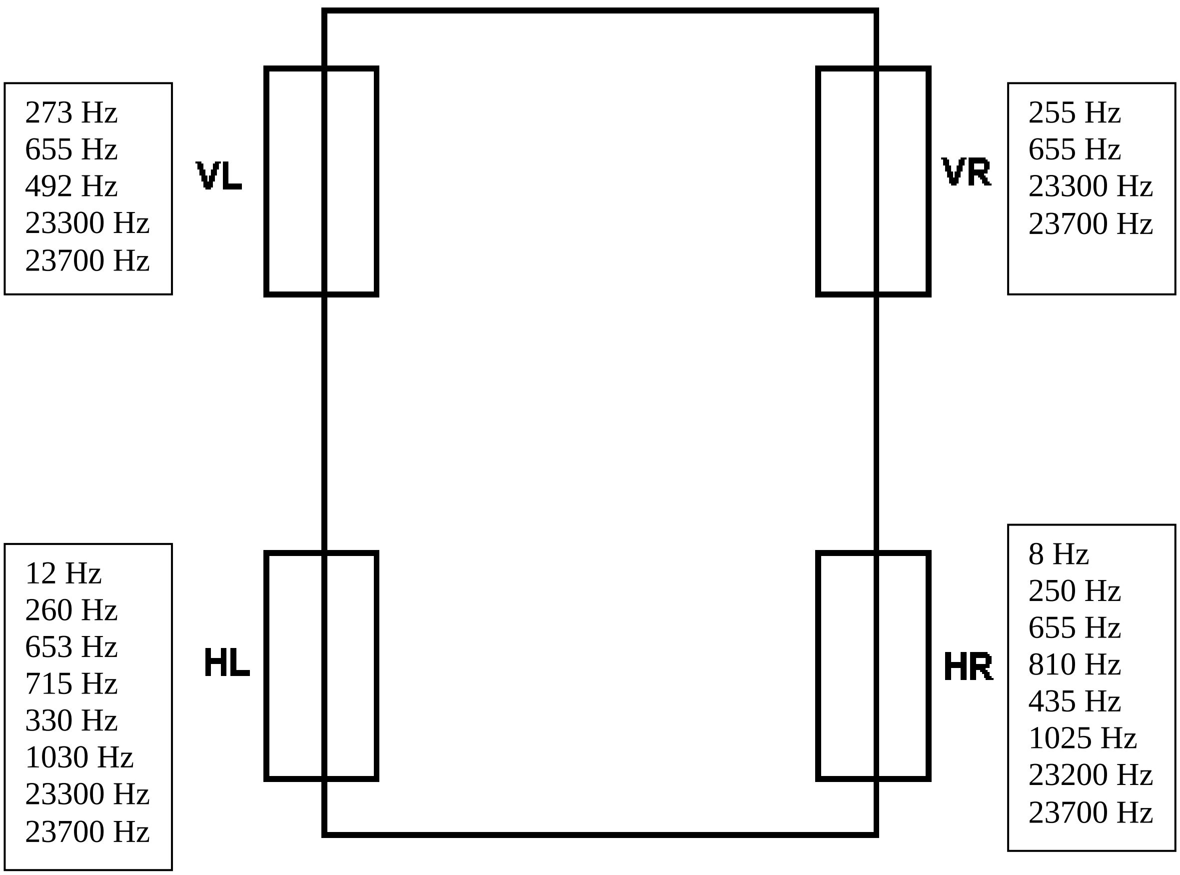

Figure 5.16: Notable frequencies of the wagon with eccentric bearing

5.4.2.2 Wagon with the wheels with defects

The notable frequencies of the wagon with the wheels with defects are represented on the following figures:

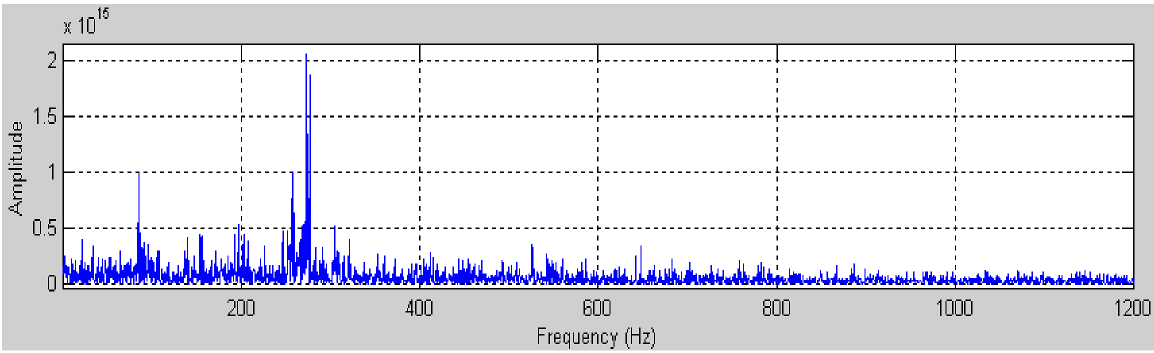

Figure 5.17: Fourier transformation in the lower frequencies for the case VL (front left wheel) of the wheels with defects

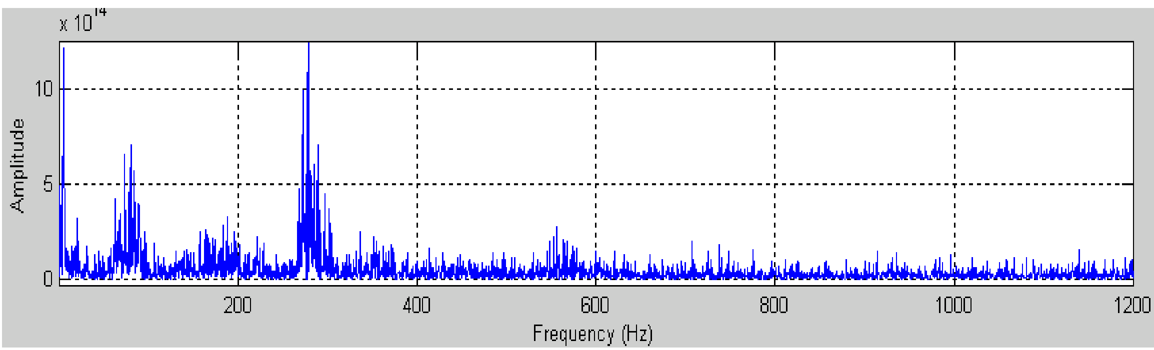

Figure 5.18: Fourier transformation in the lower frequencies for the case VR (front right wheel) of the wheels with defects

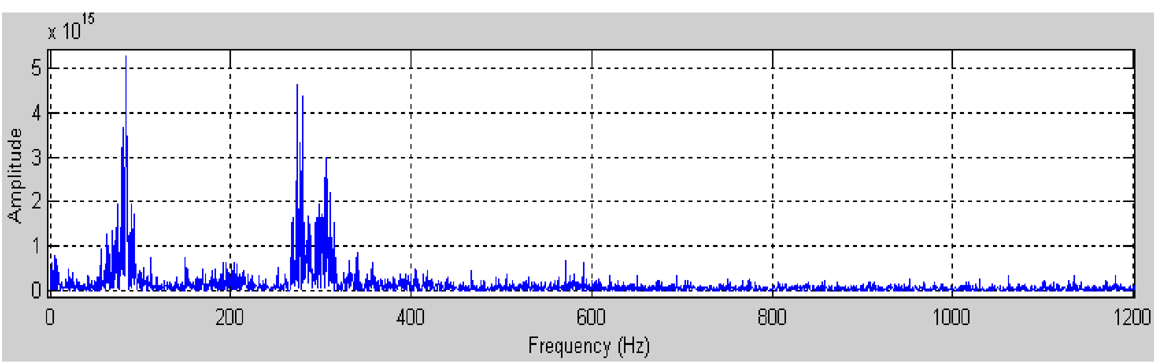

Figure 5.19: Fourier transformation in the lower frequencies for the case HL (back left wheel) of the wheels with defects

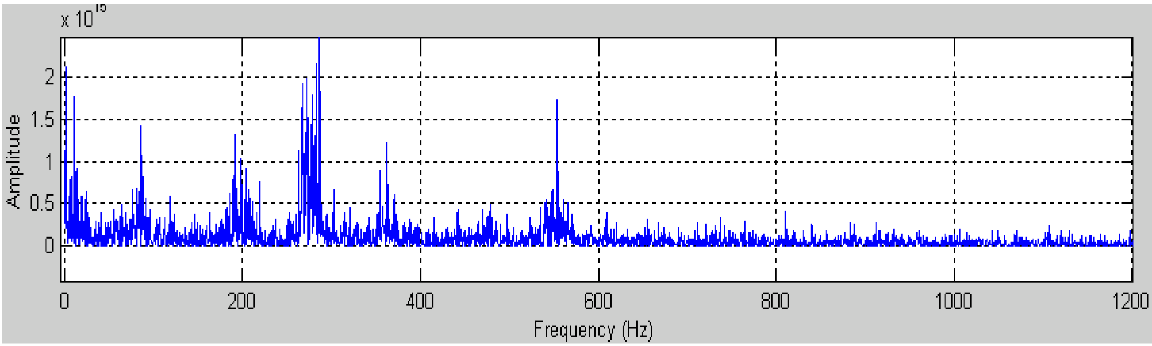

Figure 5.20: Fourier transformation in the lower frequencies for the case HR (back right wheel) of the wheels with defects

We can represent the preceding results and the ones represented on the table with the notable values of the frequency on the wagon as following:

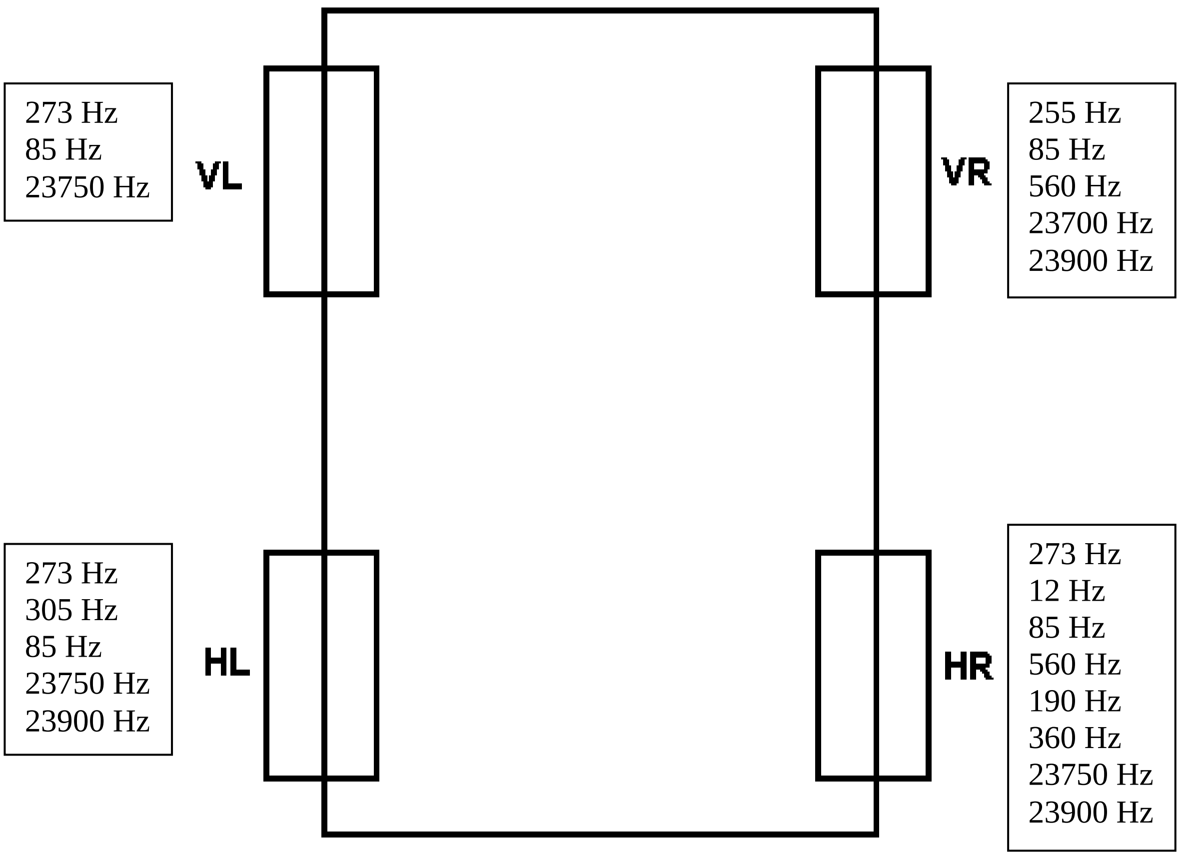

Figure 5.21: Notable frequencies of the wagon with the wheels with defects

5.4.2.3 Wagon with the polygonal wheels

The notable frequencies of the wagon with the wheels with defects are represented on the following figures:

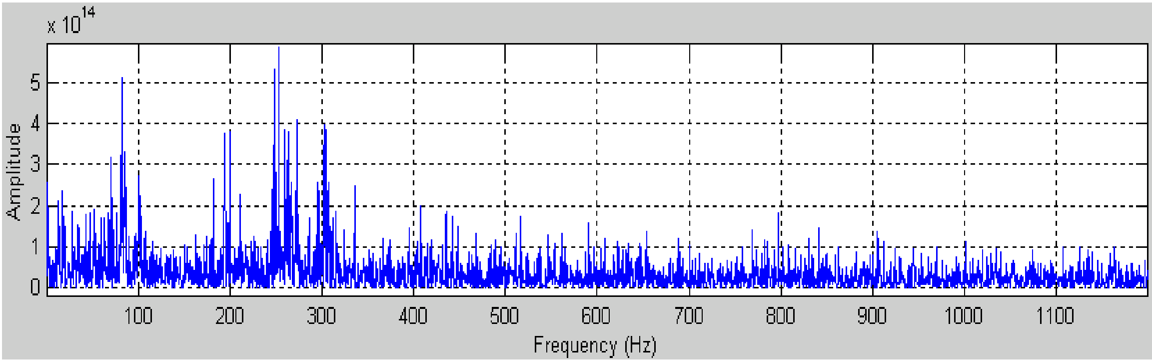

Figure 5.22: Fourier transformation in the lower frequencies for the case VL (front left wheel) of the polygonal wheels

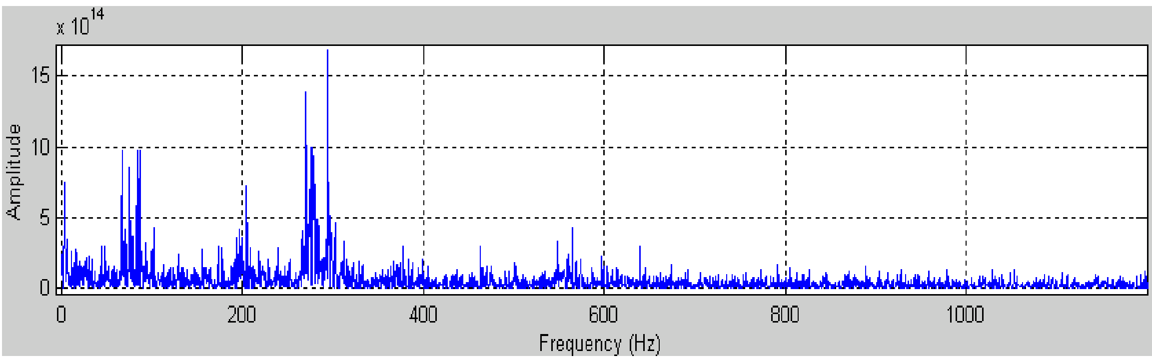

Figure 5.23: Fourier transformation in the lower frequencies for the case VR (front right wheel) of the polygonal wheels

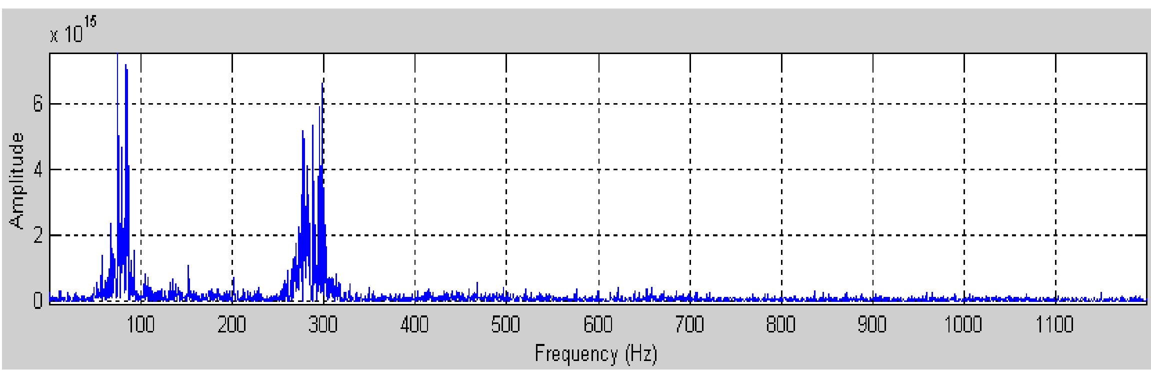

Figure 5.24: Fourier transformation in the lower frequencies for the case HL (back left wheel) of the polygonal wheels

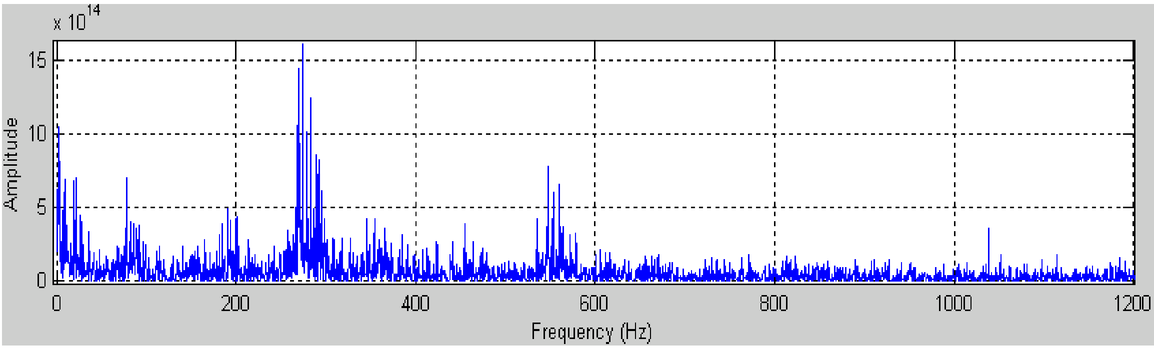

Figure 5.25: Fourier transformation in the lower frequencies for the case HR (back right wheel) of the polygonal wheels

We can represent the preceding results and the ones represented on the table with the notable values of the frequency on the wagon as following:

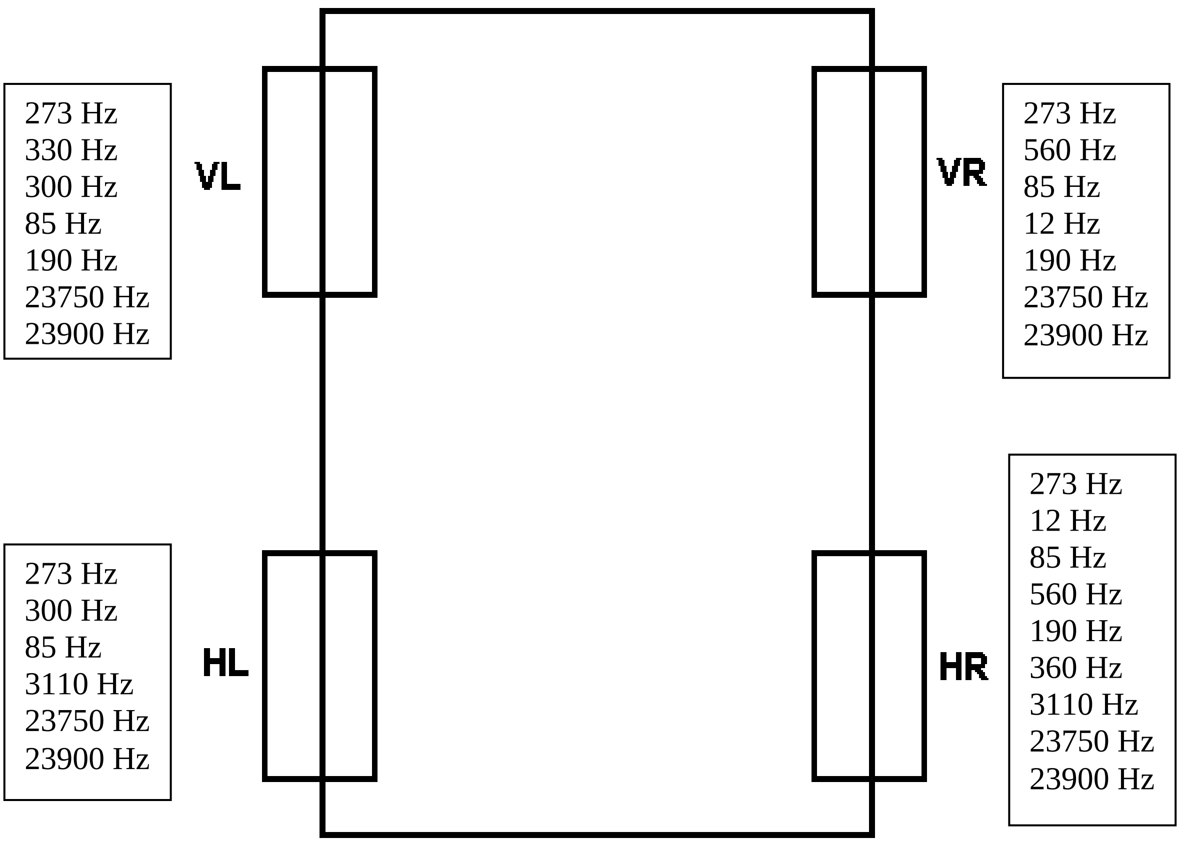

Figure 5.26: Notable frequencies of the wagon with the polygonal wheels

5.4.3 Analysis of the results

Considering the notable frequencies in different cases, we can see that the frequency around 270 Hz is always represented significantly independently from the position of the wheel and from the type of wheel. Then we can say that 270 Hz is certainly one of the resonance frequencies of the whole system.

The frequency around 85 Hz is well represented on every wheels for the polygonal and the defect cases. For the bearing case, it is not relevant. Admitting that the polygonal and the defect cases are cases that concern the surface of the wheel, we can infer from the result that 85 Hz is a frequency that is excited by excitation of the surface of the wheel. As the bearing is not a part of the wheel and the frequency 85 Hz is independent from the position of the wheel, we can say that 85 Hz is probably one of the resonance frequencies of the wheels.

The frequency around 650 Hz is represented on every wheels on the bearing case only. We can infer from this that this frequency is specific to the eccentricity of the bearing.

The frequency 560 Hz is quite well represented on the case of the defects. This means that this frequency is probably created by one of the defects of the wheel. We can also tell a similar conclusion for 360 Hz.

A notable frequency for the polygonal wheel is 190 Hz. Moreover, this frequency is quite well represented in the defect case. We can then say that this frequency appears with irregularities of the surface of the wheel.

Some other frequencies appear but without any real coherence. Those frequencies seem to be specific to one wheel but as we do not have any information of the wheels independently, it is difficult to explain the reasons of these frequencies.

Around 24000 Hz, some frequencies appear but as the time stamp frequency is 48000 Hz which is twice as more, this frequency is due to the time stamp and we do not have to consider it for the analysis of the wheel.

On the table 5.4, there are some notable results that could help to do this analysis.

5.4.4 Comparison with the results of the measurements in Kirchmöser

Considering that the train was running at a speed that was around 200 km/h, it makes sense to compare the results only with the results we had in Kirchmöser at high speed (between 50 and 220 km/h).

In Kirchmöser, we said that the resonance frequency was around 2300 Hz and the results we have with the tests on the train lead us to say that the resonance frequency is around 270 Hz. As there is no coherence between those 2 frequencies, we can say that the resonance frequencies are different. On the train, some factors that are not on the test complex of Kirchmöser make an influence to the resonance frequency.

The frequency of 85 Hz that is excited on the surface of the wheel in the case of the train is not represented on the measurements made in Kirchmöser. We can then say that the type of wheel used in the different cases is different.

Nevertheless, 300 Hz is a corresponding frequency and appear in both cases when there are irregularities on the surface of the wheel. This means that there were similar irregularities on the wheels of the train and on the wheels used during the measurements in Kirchmöser. In Kirchmöser, 300 Hz appears when there are slits. We can then infer from this that there were cracks on the surface of the wheels of the train where this frequency appears, for example the back left wheel of the case with defects. The frequency has to be considered as it is a relevant frequency for some kind of defects on the surface of the wheel.

The frequency around 3300 Hz appears on the back wheels of the polygonal case of the train and also at high speed on the cases with slits and flats. On the one had, the train was running at high speed but on the other hand, this frequency is only slightly represented in the cases of the train. This frequency comes from a similarity in the wheels as it appears when there are irregularities on the wheels. As we already said that the wheels in the 2 kinds of measurements where probably different, we can think that this frequency is coming from the type of material used which could be the same in the case of the train and of the wheelset in Kirchmöser.

5.4.5 Conclusion of the measurements on a real train

During this analysis, we could formulate an hypothesis on the resonance frequency of the system. We could also detect some frequencies specific to a special defect. Some of the frequencies where similar to the one detected in Kirchmöser, that's why we can see some similarities such as the material of the wheels or the frequencies caused by defects on the surface.

The characteristic frequencies have now to be considered for the next part of the project. Those frequencies are telling about some kind of defects, that's why they should be treated in order to tell the system the concrete information they teach us in order to take the right decision considering changing or repairing the wheel.

6 Conclusion

During this “Projet de fin d’études”, several results were achieved in contribution to the project “Intelligenter Radsatz 2000+”:

- The improvement of the SiCOM system with regression tests could help in recording data in a better way for the further analysis.
- With the help of MATLAB programs, the data that were recorded could be well analysed. Defects such as flatness, slits or holes could be detected by different sensors and analysed.
- Some significant frequencies of the system used for the measurement campaign done in Kirchmöser could be found and will be used for a further more detailed analysis of specific defects of the system corresponding to specific frequencies.

To sum up, at different levels of the project, the recording, the analysis and the understanding of the signals got from a train wheelset are getting better and better. This will enable to go further in the project until its achievement which is to be able to know the lifetime of a train wheelset.

The project “Intelligenter Radsatz 2000+” will now continue and the experiences we had will contribute in teaching what the next focus should be. In the last measurement campaign in Kirchmöser, we got some analysis information and significant frequencies. The team can now go further by analysing more in detail a special kind of defects during a next measurement campaign. Also, it was obvious that the SiCOM system has an important role to play in this project as the fact the data can be recorded simultaneously is very important for a good comparison of different signals. Nevertheless, the SiCOM system is still under development, some regression tests are performed. Moreover, an important focus for the SiCOM system team is the improvement of the synchronisation between the recording of the different channels as we have to compare signals that are recorded at the same time. The MATLAB programs that were created are now available for further analysis in the “Intelligenter Radsatz 2000+” project. Those programs were improved during the analysis in order to analyse and compare the signals in better conditions.

In this report, the reader could have an overview of the work that was done for Siemens Corporate technologies and the method used. This work, as a contribution to the project “Intelligenter Radsatz 2000+”, will be used for further analysis in the continuity of the project.

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