TECHNOLOGICAL ATTRACTION POLES

FINAL REPORT

CHASM – Coping with Health, environmental and safety Aspects in Standards for Machinery

PA-22

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March 2006

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1 Introduction to the CHASM project

1.1 Motivation and state of the art

Since the last decade a lot of EU directives have come into force of which many apply to products (the "new approach" directives based on Article 95 of the EC Treaty) and to the health and safety of workers (the "social" directives based on Article 138 of the EC Treaty).

These technical regulations affect the way products (tools, machines, engines,...) are produced taking into account the state-of-the art. Harmonised European standards are reflecting this state-of-the-art and are presumed to conform to the corresponding essential requirements of the directives. Many directives are under revision and a multitude of new directives are being developed.

Also other directives relating to the environment and sustainable development came into force (e.g. emission of engines) which have a very detailed legislation. It has not determined yet how environmental aspects will be treated within standards. In this field new directives are being developed as well.

A lot of standards developed during the last decade deal with the technical aspects of almost any product, service or process. They are not obligatory but play a crucial role in the design, manufacturing, packaging and end-of-life stages when used. They deal with people working with machinery and the efficient use of natural resources. These standards and detailed legislation have an crucial impact on the environment and as to safety at work.

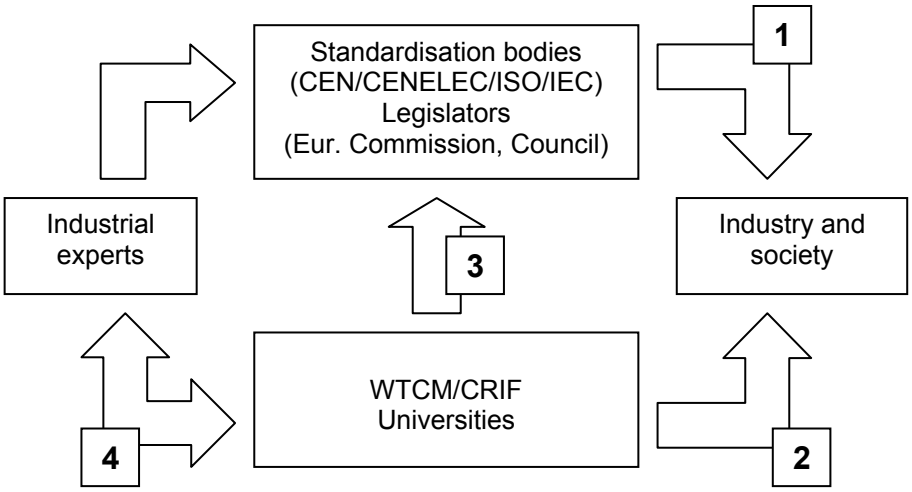
The WTCM/CRIF research center is faced with the facts that:

1. a lot of companies still have a lack of knowledge about the existing technical regulations and their related standards. They also want to be informed about the new technical directives and standards.
2. there is not enough support towards industry from research centers and universities concerning the practical application of these regulations and standards. The industry asks for solutions in order to make their products conform to directives and standards.
3. as to future directives and standards the experts of research centers- and universities are not enough involved in the legislation and standardisation process. Future legislation and standardisation is very important to industry because they will determine the way their products will be built tomorrow.
4. the research at the universities (technological and prenormative) is not always in line are with the requirements of the future directives and standards. There is no proper dialogue between industrial experts and universities and WTCM/CRIF.

The following scheme illustrates these issues.

The rectangles symbolise the actors and the arrows the information streams. The numbers symbolise the above mentioned problems

PS. The information stream from industry experts towards legislation and standardisation is not a part of the project (industrial activity)



1.2 Objectives

The main objective of the project is to contribute to solving each of these shortcomings within a well-chosen selection of directives and standardisation activities (see target group).

To solve these shortcomings the respective tasks within the project will be:

1. to inform industry by promoting standardisation and technical regulation as a useful economic and social tool that has the potential to play a larger role in protecting the environment and the health and safety of workers. This will be done by organising seminars throughout the whole country.

   These are horizontal activities organised in collaboration with National Ministries, the Belgian standardisation institute BIN/IBN, the multisectoral employers federation Agoria, the universities and WTCM/CRIF)

2. to transfer the knowledge and the results of research towards more applicable projects. This will be organised by the means of
   - specialised international seminars
   - specific projects triggered by the Belgian industry, formulated by companies in the committee of potential users.

   Thise will be "vertical" activities, organised by the universities and WTCM/CRIF

3. to participate in the standardisation activities of the Technical Committees of CEN/ISO, CENELEC/IEC related to each workpackage and to participate in the stakeholders meetings of the European Commission, international forums and the National Ministries regarding the future legislation.

4. to create a dialogue between the industrial experts and the universities and WTCM/CRIF so that the research programs will be more focussed on the technological challenges of the new directives and standards.

The numbers of the figure also represent the tasks to solve the shortcomings.

1.3 Target group and selection of technical regulations and standardisation activities

The technical regulation and standards treated within the project is aimed at machine builders (mechanical and mechatronical engineering), equipment users and persons in general.
Machine building is a strategic sector of the country with a turnover of 8 thousand million EURO and employment of 43000 people in Belgium.
The number of equipment users is much higher (669000 people in Belgium).

The project aimed to contribute to standardisation in the mechanical and mechatronical field which has an impact on the environment, health and safety. The investments of industry to make the machines more environmentally friendly and safer are very large and contribute to the benefits of the individual and whole society.

As to the environmental aspects the project dealth with:

Workpackage 1: Noise and vibration

Workpackage 2: Lifecycle environmental aspects

Workpackage 3: Emissions of engines.

As to health and safety aspects the project will dealth with:

Workpackage 4: Health and safety aspects of machinery.

Workpackage 5: Electromagnetic compatibility health and safety aspects

Background of workpackage 1: Noise and vibration:

Noise: The Fifth Environmental Action Programme of the European Commission identified noise as one of the most pressing environmental problems in urban areas and workplaces and the need to take action with regard to various noise sources.
Reducing permissible noise levels for such equipment will protect the health and well-being of citizens as well as protect the environment.

Vibration: Biodynamic research as well as epidemiological studies have given evidence for an elevated risk of health impairment due to long-term exposure with high-intensity whole-body vibration. Increased duration (within the working day or daily over years) and increased vibration intensity mean increased vibration dose and are assumed to increase the risk, while periods of rest can reduce the risk. There are not sufficient data to show a quantitative relationship between vibration exposure and risk of health effects.

Background of workpackage 2: Lifecycle environmental aspects:

The environmental impact caused over a product's life cycle - including the winning of raw materials, production, distribution, use, maintenance, and final disposal - is largely determined during the design phase, which is - in turn - significantly influenced by the specifications laid down in product standards. Therefore, it is important that environmental aspects have been taken into account while developing these product standards, as has been recognised by e.g. ISO when publishing their Guide 64 on this subject.

While for consumer product manufacturers this concern has already captured ground, at this moment in time machine constructors still have to become familiar with the emerging standards for life cycle assessment and the consequences this will have for their design procedures. This is particularly the case for small and medium size machine builders.

Background of workpackage 3: emissions of engines:

It is a fundamental principle that all persons should be effectively protected against recognized health risks from air pollution and that this necessitates in particular the control of emissions of nitrogen dioxide (NO2: acid rain), particulates (PT: carcinogenic, poisonous) - black smoke, and other pollutants such as carbon monoxide (CO: poisonous, suffocating); whereas with regard to the prevention of tropospheric ozone (O3) formation and its associated health and environmental impact, the emissions of the precursors nitrogenoxides (Nox) and hydrocarbons (HC: carcinogenic, poisonous) must be reduced; whereas the environmental damage caused by acidification will also require reductions inter alia on the emission of Nox and HC.

Background for workpackage 4: Health and safety aspects of machinery

The social cost of the large number of accidents caused directly by the use of machinery can be reduced by inherently safe design and construction of machinery and by proper installations and maintenance.
An adequate safety is enshrined in the principle of incorporating safety into the design and manufacturing of machines. When choosing the most appropriate solutions, the manufacturer must apply the following principles, in the following order:
_eliminate or reduce risks as far as possible
_take the necessary protective measures against risks that cannot be eliminated
_inform users of the residual risks due to any shortcomings in the protective measures adopted
These principles still have to be applied to a lot of machinery and safety techniques, taking into account a machine's entire lifetime, including handling, assembly, maintenance, repair and dismantling, and even in foreseeable abnormal situations. The manufacturer must also take into account the conditions of use and the constraints imposed by wearing personal protective equipment so as to minimize the operator's discomfort, fatigue and stress.

Background of workpackage 5: Electromagnetic compatibility health and safety aspects

It is imperative to protect people against established adverse health effects that may result as a consequence of exposure to electromagnetic fields. The exposure of the general public to electromagnetic fields should be balanced with the other health, safety and security benefits that devices emitting electromagnetic fields bring to the quality of life. It is therefore important to limit the emission of electromagnetic fields.

2 Workpackage 1: Noise and vibration

2.1 Description of research works

2.1.1 Context

The control of sound and vibrations becomes an important issue. European directives, national standards and legislation force machine manufacturers to control the vibration and acoustical emission of their machines. In the past, limited attention was spent to these issues, because this kind of problems was not actual and no expertise was present in small companies. It has become necessary for companies to achieve expertise or to have external expertise at their disposal.

2.1.2 Targets

This project aims at:
- to make the expertise present at the research institutions available to the machine manufacturers;
- to apply the research results applicable to methods and directives to improve existing standards and to generate new standards;
- to create a dialog between industry and research institutions to direct the research programs to future technological developments to satisfy the new directives and standards.

2.1.3 Scientific method and results

2.1.3.1 **Introduction.**

To exchange expertise, some actual topics are selected:
- Prediction methods for emission of structural sound from machines.
- Acoustical characterisation of sound sources of fluid machines and characterisation of silencers.
- Active noise and vibration control.
- Accelerated durability and comfort testing of machine components.
- Preparation of a CEN technical report for all possible vibration levels which appear at machines not functioning on the road.
- Dissemination of the changes made on the 2000/14/EG directive concerning the sound emission of outdoor machines.

2.1.3.2 **Prediction methods for emission of structural sound from machines.**

Numerical simulation of vibro-acoustic systems is usually done by finite element or boundary element methods. Both deterministic techniques are based on an element discretisation of the problem domain or its boundary surface. The dynamic variables within each element are expressed in terms of simple (polynomial) shape functions, which do not satisfy the governing dynamic
equations. These element based methods are well suited for the dynamic analysis of arbitrarily shaped (vibro-acoustic) systems, but their use is practically restricted to low-frequency applications. At higher frequencies, structural and acoustic wavelengths become so small that a prohibitively large number of elements and computational effort would be required to get reasonable prediction accuracy.

In order to extend the applicability of numerical prediction techniques towards vibro-acoustic analysis at higher frequencies, the PMA division has developed a wave based method (WBM). The WBM is a deterministic technique, based on the indirect Trefftz approach. Instead of using locally defined element shape functions, the WBM applies globally defined wave functions, which do satisfy the governing dynamic equations. The vibro-acoustic response of the system at a certain frequency is expressed as a summation of wave function contributions, which result from an integral formulation of the problem boundary conditions.

The WBM exhibits better convergence properties than the element methods resulting in smaller model sizes and computational efforts. However, the WBM is most efficient for systems of moderate geometrical complexity. The PMA division has proven the theoretical feasibility in previous studies. The research activities in recent years have focused on three items. A first item involves the extension of the wave modelling concept towards exterior acoustic radiation modelling in unbounded domains. In a second item, research focused on the dynamic modelling of three-dimensional mechanical structures consisting of arbitrary flat plate assemblies. A third item is the development of a hybrid method, which is based on a coupling between the WBM and finite element based methods. This hybrid approach aims at combining the benefits of both techniques, namely the high computational efficiency of the WBM and the geometrical flexibility of finite element methods. A typical example is presented by figure 1 which is the simulation of the sound field in a car interior excited by external source, such as the windscreen wiper in air flow.

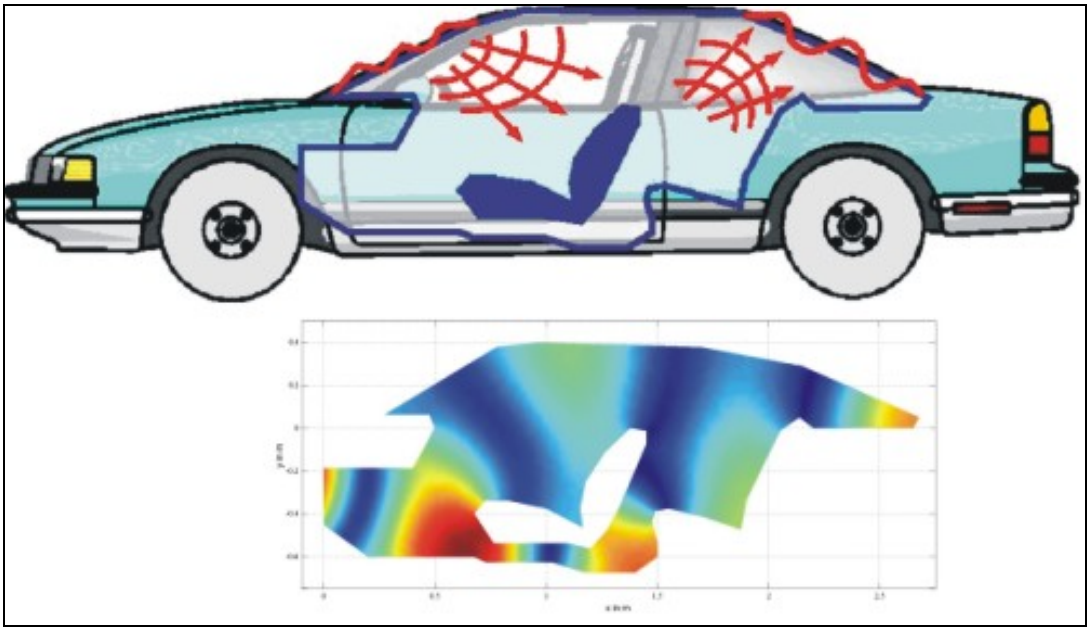


Figure 1

Another practical application is the study of noise produced by power transformers. The study has been carried out in a wider framework that investigates the noise radiation characteristics of air-cooled power transformers. The dynamics of the transformer core structure plays a significant role in the noise generation process. The reported work focuses on the influence of lamination of the core block on its structural dynamic behaviour. The degree of lamination of a core and its boundary conditions have been found to have a strong influence on its resonant behaviour and the need for an accurate modelling of these physical details has been observed through this combined experimental-numerical study.

2.1.3.3 Acoustical characterisation of sound sources of fluid machines and characterisation of silencers.

2.1.3.3.1 Determination of the acoustical characteristics of an internal combustion engine.

This study concerns the ISO-10534-2 standard. This standard treats the two microphone transfer function method wherewith the absorption coefficients and the acoustical impedances of silencers or sound isolation materials is measured. This standard remains very vague with respect to the calibration of the measurement setup. However, this calibration is crucial for the quality of the result. This research project has resulted in an improved calibration method. Finally, the method is applied to measure the acoustical impedance of an internal combustion engine exhaust.

The following aspects of the transfer function method will be treated:
- Calibration of the setup;
- Avoidance of physical phenomena introducing measurement errors;
- Check through electrical analog models.

Calibration of the measurement setup.

The measurement setup consists of a wave guide connected to the unknown impedance. In the wave guide, two microphones are positioned at two discrete locations. The transfer function between the two microphones will be measured. Then, the reflection coefficient and the acoustical impedance is derived from the transfer function. This calculation is extremely sensitive to deviations, particularly the microphone positions.

To correct for the microphone positions, the ISO-10534 procedure prescribes to measure the microphone locations using a caliper. During the measurement of the transfer functions, the atmospheric pressure and the temperature needs to be logged to determine the speed of sound. The speed of sound and the microphone positions determine the phase between the microphones. This procedure is not sufficiently accurate to measure impedance. As result, the impedance amplitude and frequency ranges are too small.

In the new method, the phase measurement between the microphones is realised using transfer functions between the two microphones. Hereby, the wave guide end where the unknown impedance will be measured is closed at two different positions. Full reflection of the incident sound waves takes place. The positions of the microphones will now be determined by the times the waves need to travel from the wave guide end to the respective microphone locations. At a well determined frequency, a standing wave of a quarter wavelength between the wave guide end and the closest microphone position is present. Such a standing wave exist also between the wave guide end and the farest microphone position. The transfer function between both microphones exhibits a pole and a zero at these respective frequencies. The wave travelling times between the two microphone positions and the wave guide end can now be determined end used as calibration of the microphone positions. These obtained travelling times are still not sufficiently accurate in the high frequency range. The corresponding impedance is very sensitive to deviations and will be used the refine the travelling times. The measured impedance has the highest accuracy at the frequencies where a half wave length occurs between the respective sensor locations and the wave guide end. The observed impedance is the impedance of a small piece wave guide. The length of this piece wave guide can be determined accurately and be used to correct the microphone positions. This approach is an order of

greatness more accurate than measuring distances as proposed in the ISO-standard. This method has the following improvements in comparison to the ISO 10534-method:

- the determination of the sound speed from the atmospheric pressure and temperature has become superfluous.
- interchanging the microphones is not necessary.
- amplitude and phase calibration of the microphones are not necessary.
- larger impedance measurement range in a wider frequency range.

Application of the method on a combustion engine.

This measurement method is used to determine the acoustical impedance of the intake and the exhaust port of an engine. To obtain an accurate measurement on the engine, attention must be paid to the following issues:

- The gas flow generated by the engine causes three error sources:
  - The speed of the gas flow is superposed on the speed of sound. This error can be corrected.
  - The gas flow causes turbulence which damps the waves already present in the wave guide. This error cannot be corrected.
  - This turbulence generates additional sound. This error cannot be corrected.
- The temperature gradient causes a non-uniform sound speed in the wave guide.
- The sound generated by the engine itself mixes with the reflected waves and disturbs the reflection coefficient measurement.

These problems make an accurate acoustical impedance measurement on an operational engine impossible. Therefore, the measurements are made in non-operational modes of the engine, i.e. the engine runs without fuel. To include the piston and valves movements in the measurement, the engine is run electrically. The intake is sealed to prevent gas flow. In this way, the acoustical impedance of the engine exhaust can be measured. The setup is presented in the figure 2.

Figure 2

For verification, an electrical analog circuit of the engine has been created. In the model, the engine cylinders are represented as capacitors, the exhaust valves as resistors en the exhaust manifold as transmission lines. The impedance, simulated from this model, matches surprisingly well the measured impedance. The figure 3 present the simulation and figure 4 the experimental results.

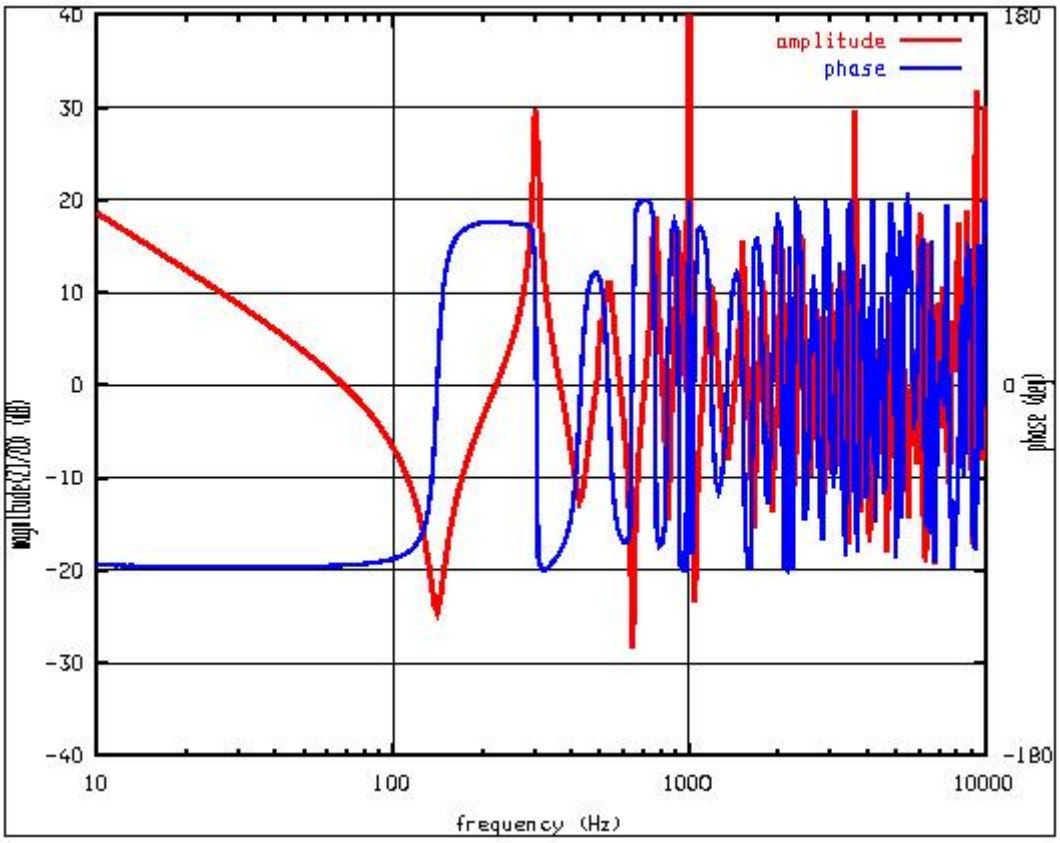


Figure 3.

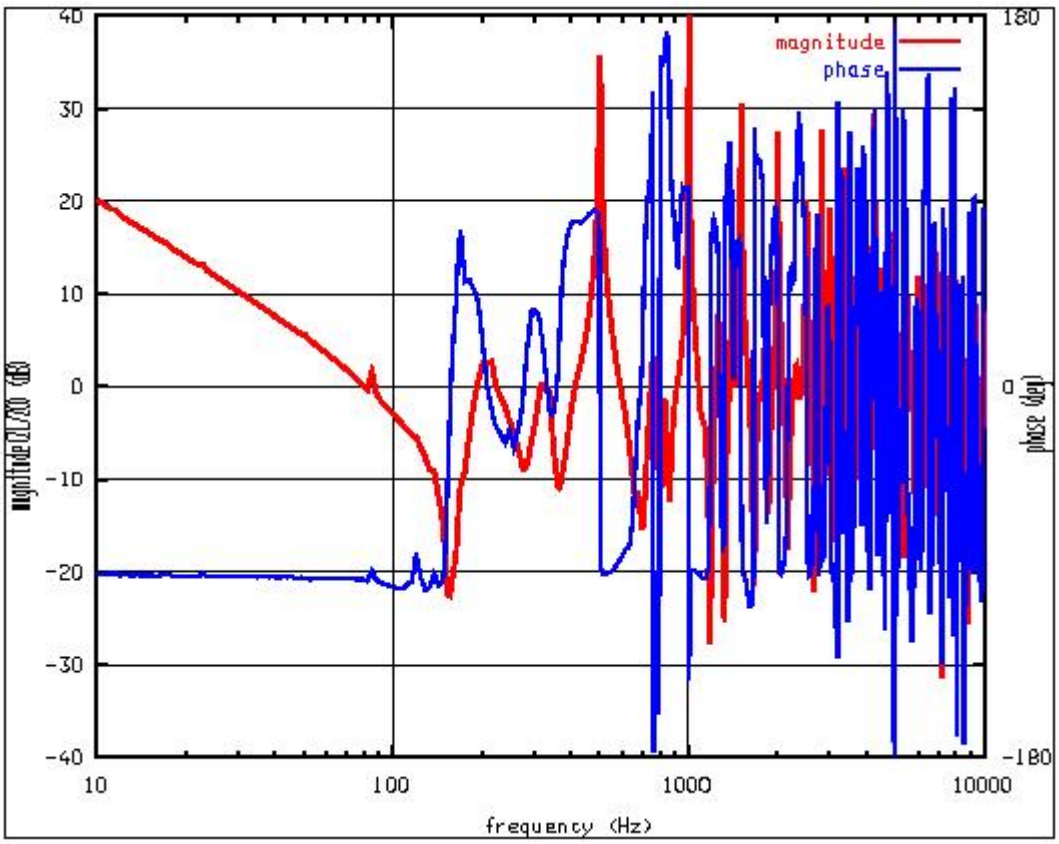


Figure 4

2.1.3.4 **Active noise and vibration control for machines.**

During the last decades, intensive research in active noise and vibration control has been conducted. A major part is directed to new and improved control algorithms, improved actuators and sensors. Also at the KULeuven PMA, research has been carried out which has led to interesting applications, relevant for industry.
The most recent investigations are directed towards following applications:

- Active silencer for internal combustion engines.
- Active structural control for pulsating machines (like punching machines, etc...)
- Active bearings.
- Development of a lightweight inertial actuator with integrated velocity sensor.
- Development of a power inertial actuator.

2.1.3.4.1 Active silencer for internal combustion engines.

New European directives force engine manufacturers to develop clean, fuel efficient and silent engines. Hereby, the emphasis is to improve the engine thermal efficiency. Also, exhaust system manufacturers have to develop new concepts of exhaust systems to comply the noise emission requirements with a reduced engine back pressure, so that the engine efficiency is not influenced adversely. At the KULeuven, a new kind of exhaust system has been developed.
Its principle is based on an electrically controllable valve combined with a buffer volume. In contrary to the until now known systems, this system is able to reduce the exhaust noise without passive silencers prior to the active system. The system is developed such its back pressure and electrical power consumption are small.

Principle of the active silencer.

A combustion engine behaves as a volume velocity source. The amount of gas present in the cylinder will be completely scavenged by the piston. Placing a valve in the exhaust duct has no effect on the volume velocity when no capacitive elements are present between the engine and the valve. This observation has led to a new concept of silencer composed of a controllable valve combined with a buffer volume. The control valve modulates the gas flow produced by the engine such that the flow fluctuations to the atmosphere, which are responsible for the exhaust noise, are minimised.
In this concept, the back pressure can be chosen arbitrary en eventually adapted when the operational circumstances this require. The choice of the back pressure determines directly the size of the buffer volume and the required control valve performance. In most cases, the volume of the buffer is the limiting factor. The sound reduction capability depends only on the controller performance and the initial flow resistance of the control valve.

Development of the active silencer.

In this investigation, all the necessary instruments have been developed to realise an active silencer. These tools include the acoustical characteristics of an engine, the use and expand of electrical analog circuitry wherewith the engine, active silencer and controller can be simulated sufficiently accurate. The use of electrical circuits visualises the problem and allows physical interpretation without prior solving the system's differential equations. Also the capability of solving physical coupled multi-domain (electrical, mechanical, acoustical, etc...) models in one global model is a great advantage. Particularly, the engine, the active silencer and the controller is simulated in one single electrical analog circuit. The simulation software used calls SPICE. The simulation results are sufficiently accurate to construct an experimental prototype based on the simulation results.

Also, a cold engine simulator test setup, presented in figure 5, has been developed which generates exhaust noise and the matching gas flow using pressurised air.

Figure. 5

The acoustical impedance and the source spectrum are similar to an operational engine. The cold engine simulator allows to carry out reliable acoustic and fluid-dynamic experiments with exhaust systems build from low cost materials and using standard measurement equipment. The experimental results can be reliably extrapolated to operational engines.
An operational engine generates the exhaust sound by the gas discharge which happens when the exhaust valve opens. The discharge takes only a few milliseconds. During the discharge, the volume change of the cylinder due to the piston movement remains very small. The gas discharge can be considered as a discharge at constant volume under pressure.
The cold engine simulator principle is based on the discharges of constant volumes which are previously charge by pressurised air. The setup has been build from a regular engine block, wherein the pistons are fixed at their lower dead points. The camshaft is electrically driven and compressed air is applied at the inlet collector. When the intake valve opens, the cylinder pressurises. Then the intake valve closes and the exhaust valve opens. The enclosed gas discharges into the exhaust.
The active damper has been built and evaluated on the cold engine simulator. Four control strategies have been tested, i.e. a fixed feedforward controller, an adaptive feedforward controller, a feedback controller and an iterative learning controller. The first three controller types perform similarly and realise exhaust noise attenuation in a frequency range of 100-150Hz.
The iterative learning controller, developed originally in the framework of the research of silencing punching machines, is able to attenuate exhaust noise in a frequency range until 1kHz.

The active silencer is able to attenuate engine exhaust noise generated by the discharge of cylinder pressures of 400kPa. The noise reduction by activating the controller amounts 10 to 13dB (3 to 5 dBA) with 10kPa back pressure and an electrical power consumption of 5W.

2.1.3.4.2 Active structural control of pulsating machines (punching machines etc...).

Many kinds of industrial production machines generate a pulsating noise. Pulsating noise does not mean a regular pulsation like engines or compressors, which pulsation can be considered as composed of harmonic components. The indicated pulsation noise is irregular, for example punching machines, presses, assembly lines etc... This research has been started recently and focuses on active systems, which incorporate the specific properties of pulsating noise.
The following configurations has been investigated:

- - Acoustic control of pulsating noise generated by an acoustic source ("airborne sound").
- - Acoustic control of pulsating noise generated by for example machine frames ("structure borne sound").

The current research focuses on a machine frame of a CNC-controlled punching machine. Several active control strategies are experimented with, first on a simple steel plate, then on a demonstrator punching machine. This demonstrator punching machine, presented in figure 6, is a simplified version of an existing machine, whereupon measurements has been carried out and analysed.

Figure 6

The most important noise generating phenomena observed at the original machine are introduced in the demonstrator. The machine frame vibrations are controlled using inertia actuators and accelerometers. As control strategies, linear time-invariant feedback and iterative learning control has been experimented with.

During the research project, a new iterative learning control algorithm has been developed. The algorithm uses information of the previous impacts to generate the control action for the next impact. This information needs to be filtered by two control filters and is then stored in a memory. An external trigger signal announces the next impact to the controller, which sends the control signal prior to the event. This type of controller allows application of non-causal filters. These filters allow phase lead in combination with amplitude roll off. Using this property, controllers can be designed to cancel vibrations in complex structures with a high modal density in a high frequency range, typically 1kHz. Figure 7 demonstrates the capabilities of the new controller.

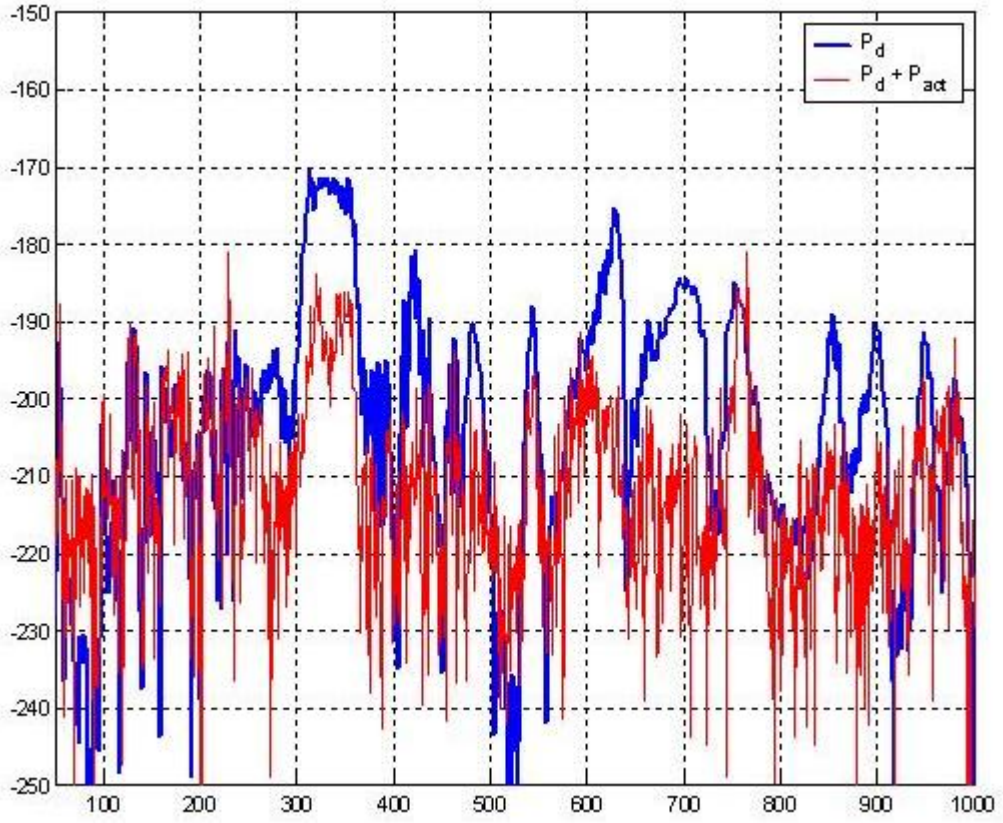


Figure 7

2.1.3.4.3 Active bearings.

The vibrations caused by rotating machine parts find their way to large radiating structures through the bearings. Examples are gearboxes, cam mechanisms, car bearings, etc.... Active bearings offer the possibility to isolate vibrations generated by rotating machine parts. The most important applications of active bearings in vibration control are:
- Active vibration isolation.
- Active unbalance compensation.
- Relative tracking compensation.

Possible active bearing principles are:
- Magnetic bearing: In the bearing housing, an electro-magnet is built in. The axis position is measured by a sensor. A controller and a power amplifier keep the axis in the desired position.
- Hydraulic bearing: The axis rotates in a hydrostatic bearing where around at strategic positions hydraulic or piezo-electric actuators are employed. These actuators control the oil pressure locally en control the axis position. The position sensors can be located in the bearing, but can

also be outside the bearing to compensate relative movements, for example the position of a milling spindle relative to the work piece to compensate elastic deformation of the machine frame.

2.1.3.4.4 Active magnetic bearings ("AMB's").

Active magnetic bearings are already commercially available and used in several applications. These bearings function contactless and oil free and therefore suitable for very high rotational speeds. They are also applied in clean environments like food industry, pharmaceutical industry, clean rooms in optical and electronic (IC's) industry and in vacuum environments.

Active vibrations isolation.

In the case wherein the controller the axis position controls using a displacement signal, the axis-bearing combination will exhibit a mass-spring behaviour with an eigenfrequency about the bandwidth of the control loop. Within the bandwidth, radial vibrations of the axis can be reduced. However, the control action introduces vibrations in the bearing housing. Outside the control bandwidth, vibrations from the axis will be isolated. The isolation factor can be adjusted by adapting the control bandwidth, based on the working regime and the desired bearing stiffness. If the controller uses a velocity signal, active damping can be achieved in the bearing.

Active unbalance compensation.

As the magnetic bearings are suitable for very high rotational speeds, unbalance forces are important. These forces can be compensated actively by controlling the magnets.
For low rotational speeds, (until +/- 5000rpm), the rotor acts as a rigid body. Any static unbalance can be compensated with a single action by adapting the mass distribution in the two planes perpendicular to the axis centre line. In these cases, active unbalance compensation is not necessary. At higher rotational speeds, the axis elasticity becomes important. Then, modal balancing needs to be applied. Modal balancing implies that each axis mode whithin the rpm-range the axis runs through, every mode shape needs to be balanced. This way of balancing is possible because the modes are orthogonal. However, at higher modes, deviations to the orthogonality property occur, for example caused by damping. It becomes difficult to balance these modes without introducing unbalance in the lower modes.
An active bearing is capable to compensate such kind of unbalances by compensating the unbalance force acting on the bearing. However, this puts additional requirement at the bearing configuration. The bearing must be capable to generate a rotating force field.

Relative tracking compensation.

At normal vibration suppression, the aim is to fix the axis position. However, it is also possible, for example metal cutting machines, that the axis needs to carry out small displacements relative to another object, such as a work piece. When for example a milling tool makes contact with a work piece, it will vibrate due to the intermediate cutting of the tool. Using active bearings, the spindle can be controlled such the vibration of the spindle compensates the vibration of the work piece. In this way, milling accuracy can be improved.

A literature study has been carried out. This part of the research has been discontinued. It has been observed that the application area is quite limited, and it will be extremely difficult to include active controlled electromagnetic actuators in high stiffness bearings of machines.

2.1.3.4.5 Development of an inertia actuator with integrated velocity sensor.

The project deal with the design and implementation of a self-sensing, electro-dynamic, inertial actuator prototype for active vibration control at a lightweight panel. After having compiled requirements, such as an actuation force of 3N and a moving mass of 20g, first an analytical analysis of an electro-dynamic actuator is carried out and optimised using electromagnetic finite element analysis (FEA). Second various solutions for inertial, or also called proof-mass, actuators focusing on the suspension are studied analytically and by FEA and a solution appropriate to the application is designed. Its dynamic behaviour is also verified using a FEA. In order to realise a self-sensing actuator a secondary measurement coil is included in addition to the driving coil. Drawings are realised on a computer aided design (CAD) system. Then actuator parts are manufactured and the actuator coil is wound with a special winding tool. The electrical driving circuit and electronics for induced voltage feedback in the secondary coil and velocity measurement are realised. A photograph of the assembled actuator without upper cover is shown in figure 8.

Figure 8

During experimental verification, a power input of 2. 2W at a continuous force of 2.5N is found as upper continuous limit. A transient peak force of up to 4.2N is expected. The weight of the moving mass is 22g with a total actuator mass of 46g or 34g without upper cover. These characteristics are considered to be appropriate for the application at a lightweight panel. Dynamic measurements of the frequency response function (FRF) between current amplifier driving voltage and transmitted force show a usable frequency bandwidth for active vibration control starting at about 50Hz up to about 800Hz. When the induced voltage in the secondary coil is fed back damping is added to the low frequency resonance due to the inertial mass

suspended on a spring and the usable frequency bandwidth for force feedback is increased to about 1kHz as is shown in Figure 9 for two different velocity feedback gains (faint solid and dashed line) compared to the open loop case (thick solid line). Due to transformer coupling between the two coils velocity measurements are limited to about 70Hz, but feedforward electronics increase the velocity measuring bandwidth to about 200Hz. The self-sensing actuator is experimentally verified on a thin aluminium plate structure, excited by an external shaker.

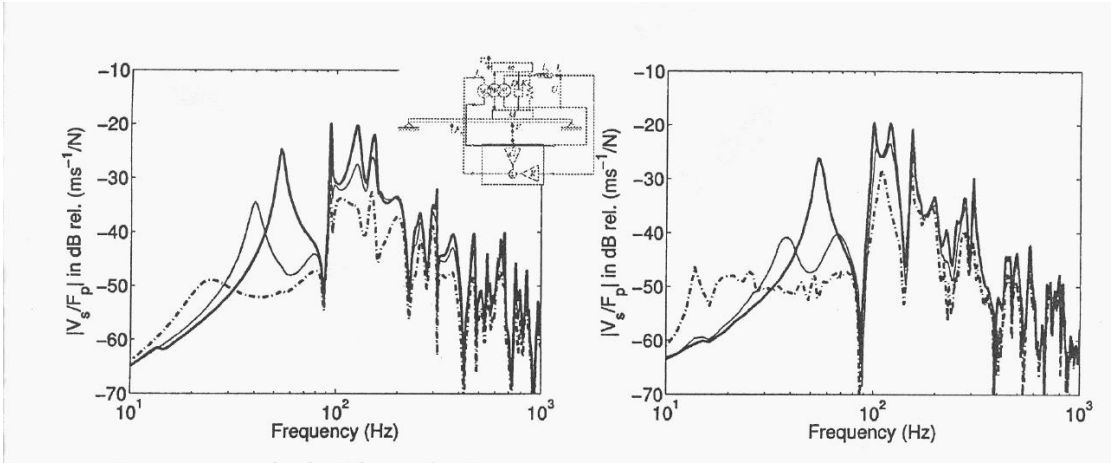


Figure 9

After the successfull realisation of the lightweight actuator, a high power (500W electrical) inertia actuator is under development. The actuator should produce 100N continuous force, 240N peak force in a frequency range between 50hz-1kHz. One of the key problems of inertia actuators is the guidance of the moving mass. The stiffness of the mass suspension must be small in the direction of the movement, the stiffness in the directions perpendicular to it must be high. The stiffness ratio should exceed a factor 1000. For this actuator, a new guidance system has been developed, such this stiffness ratio can be reached and the actuator is usable in all orientations (i.e. on moving structures). The first prototype is under construction. Its actual state is presented in figure 10:

Figure 10

2.1.3.5 **Accelerated durability and comfort testing of machine components.**

In 2003, the KULeuven PMA-group has invested is a six degree of freedom vibration shaker table. The shaker table has a hydraulic actuation mechanism and is able to generate 10 g in the three translation direction with a payload of 450 kg in a frequency range of 0-250 Hz. The maximum displacement is 50 mm in vertical and 25 mm in horizontal directions. The vibration time history of each degree of freedom can be programmed. At this instant, the university of Leuven is the only university in Europe equipped with such facility. This shaker table is used for automotive research, particularly to investigate the vibration transfer between the road to the car interior through the wheel suspension. The road profile will be programmed and in this way, realistic road excitation signals will be used as excitation. The investigation of tire vibrational response under impact excitation is a new topic that started in 2005. During the project, several services are supplied to industry, such as:

- The measurement of the dynamic behaviour of a bicycle carrier for the Flanders Drive Engineering Centre;
- Simulation of a transport load on the K600 measurement system of Krypton;
- The measurement of the dynamic behaviour of a caravan, testing the road behaviour on the excitator and fatigue testing of a sample material for the landers Drive Engineering Centre.
- The measurement of the dynamic behaviour of a caravan, testing the road behaviour on the excitator and fatigue testing of a sample material for the Flanders Drive Engineering Centre.
- The measurement of the dynamic behaviour of a pick-up for the Flanders Drive Engineering Centre.

2.1.3.6 **Preparation of a CEN technical report for all possible vibration levels which appear at machines not functioning on the road.**

The Physical Agents Directive for Vibration (2002/44/EC) which will come into force at 2005-06-06 is asking employers to observe exposure action and limit values for hand-arm and whole-body vibration as regards the exposure of workers operating equipment arising risks from vibration. Especially for earth-moving machinery is an equipment category where the determination of those risks is rather difficult due to permanently changing operating and terrain conditions.

An increasing number of inquiries to the machine suppliers (related to 2002/44/EC) show the urgent demand to prepare supporting material for the customer which have to comply with this Directive.In addition there are indications from governments of several EU countries, that product specific supporting material can be referred to for the practical implementation of 2002/44/EC in their countries.
After consultation with contractors associations in several EU countries and supported by the Committee for European Construction Equipment (CECE) we together with Indsutry and DIN proposed the elaboration of a Technical Report compiling expected whole-body vibration emission data for relevant earth-moving machinery at typical machine applications for different categories of machine size.
After approval by CEN/TC 151 and ISO/TC 127 this Technical Report will be elaborated as a joint standardisation project of both committees under the Vienna Agreement (ISO lead). A co-operation with the Technical Committees CEN/TC 231 and ISO/TC 108 dealing with "Shock and vibrations" was established.

2.1.3.7 **Dissemination of the changes made on the 2000/14/EG directive concerning the sound emission of outdoor machines.**

Within the framework of this directive, a technical report will be delivered by an advisory committee of the Commission. As the progress of that report is very slow, there was a limited active cooperation to the sound emission aspects in this report.

2.2 Diffusion and valorisation

2.2.1 Publications

- H. KIDO, H. KUAHARA, E. BRECHLIN, R. BOONEN, "Modeling the sound source of an intake and predicting the intake sound pressure level for a motorcycle", Proc. of the Small Engine Technology conference, Madison, Wisconsin, 15-18 September 2003, CD-ROM nr. 2003-32-0058/200334358.
- W. DESMET, B. PLUYMERS, P. SAS, "Vibro-acoustic analysis procedures for the sound insulation characteristics of agricultural machinery cabins", Journal of Sound and Vibration, Vol. 266, 2003, 407-441.
- B. PLUYMERS, A. HEPBERGER, W. DESMET, H. PRIEBSCH, D. VANDEPITTE, P., "Experimental validation of the wave based prediction technique for the analysis of the coupled vibro-acoustic behaviour of a 3D cavity", Proc. of Second MIT Conference on Computational Fluid and Solid Mechanics, Boston, Massachusetts, USA, Vol. II, 1483-1487.
- B. VAN HAL, W. DESMET, D. VANDEPITTE, P. SAS, "Coupling of the finite element method and a Trefftz method for steady-state acoustic modelling", Proc. of 10th International Conference on Sound and Vibration, Stockholm, 7-10 July 2003, 2809-2816.

- B. PLUYMERS, W. DESMET, D. VANDEPITTE, P. SAS, "On the use of a Wave Based prediction technique for steady-state structural-acoustic radiation analysis", Proc. of the International Workshop on MeshFree Methods (IWMM2003), Lisbon, 2003, 177-183.
- B. PLUYMERS, W. DESMET, D. VANDEPITTE, P. SAS, "A Trefftz-based prediction technique for multi-domain steady-state acoustic problems", Proc. of Tenth International Congress on Sound and Vibration (ICSV10), Stockholm, 2003, 2833-2840.
- F. DE CONINCK, W. DESMET, P. SAS, D. VAES, " Shock and vibration testing using a high-frequency 6-DOF hydraulic shaker table", Proc. of 74th Shock and Vibration Symposium, San Diego, 27-31Oct. 2003, CD-ROM.
- W. DE ROECK, W. DESMET, P. SAS, " Predicting the aerodynamically generated noise in 2D-expansion chambers using a combined LES/LEE approach", Proc. Euromech 449 Colloquium on Computational Aeroacoustics, December 9-12, Chamonix, 2003, 149-153.
- F. DE CONINCK, W. DESMET, P. SAS, D. VAES, "Multisine shock and vibration testing using a high-frequency 6-DOF shaker table", Proc. of 10th International Conference on Sound and Vibration, Stockholm, 7-10 July 2003, 1205-1212.
- G. PINTE, W. DESMET, P. SAS, "Active control of impact noise in a duct", Proc. of 10th International Conference on Sound and Vibration, Stockholm, 7-10 July 2003, 3727-3734.
- B. PLUYMERS, C. VAN MAELE, B. VAN HAL, W. DESMET, D. VANDEPITTE, P. SAS, " A new numerical prediction technique for structural-acoustic harmonic analysis in automotive applications", Proc. of the 1st Flanders Engineering Ph.D. Symposium, Industry Ready-Innovative Research, Brussels, Belgium, 2003, CDROM.
- BOONEN R., SAS P.,"Calibration of the two microphone transfer function method to measure acoustical impedance in a wide frequency range", Proceedings of the 2004 International Conference on Noise and Vibration Engineering, ISMA2004, Leuven, Belgium (2004), pp. 325-336
- R. BOONEN, P. SAS, "Ontwikkeling van een actieve geluidsdemper met akoestische karakterisatie van verbrandingsmotoren." NAG-jounal, paper nr 171-4, mei 2004 (CDROM).
- GREGORY PINTE, RENE BOONEN, WIM DESMET, PAUL SAS, "Active structural acoustic control of repetitive impact noise", Proc of the joint congress CFA/DAGA'04, March 22-25, 2004, Strasbourg, France (CDROM)
- PINTE G., BOONEN R., DESMET W., SAS P. 'Active structural acoustic control of impact noise', Proceedings of the 2004 International Conference on Noise and Vibration Engineering, ISMA2004, Leuven, Belgium (2004), pp. 55-74
- PLUYMERS, B., DESMET, W., VANDEPITTE, D., SAS, P., Application of an efficient wave based prediction technique for the analysis of
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- MASTI RAVISH S., DESMET W., HEYLEN W., On the influence of core laminations upon power transformer noise, Proceedings of the 2004
- International Conference on Noise and Vibration Engineering, ISMA2004, Leuven, Belgium (2004), pp. 3851-3862
- PAULITSCH C., GARDONIO P., ELLIOTT S.J., SAS P., BOONEN R., "Design of a Lightweight, Electrodynamic, Inertial Actuator with Integrated Velocity Sensor for Active Vibration Control of a Thin Lightly-Damped Panel", Proceedings of the 2004 International Conference on Noise and Vibration Engineering, ISMA2004, Leuven, Belgium (2004), pp. 239-254

- BOONEN R., SAS P.,"Calibration of the two microphone transfer function method to measure acoustical impedance in a wide frequency range", Fortschritte der Akustik, DAGA05, March 14-17, 2005, Muenchen (Germany).
- G. PINTE, W. DESMET, P. SAS, Active control of impact noise, Submitted for publication in Journal of the Acoustical Society of America.
- G. PINTE, R. BOONEN, W. DESMET, P. SAS, Active control of impact noise in punching machines Proceedings of the VDI conference "Schwingungen in Verarbeitungsmaschinen", Leonberg, 26-27 April, 2005, 403-420.
- G. PINTE, R. BOONEN, P. SAS, W. DESMET, Active control of impact noise of punching machines, Proceedings of the 12th International Conference on Sound and Vibration, Lisbon, 11-14 July, 2005
- G. PINTE, R. BOONEN, P. SAS, W. DESMET, Iterative learning control algorithms for the active control of impact noise, Proceedings of Benelux Meeting 2005 on Systems and Control, Houffalize, 22-24 March, 63.
- PLUYMERS B., DESMET W., VANDEPITTE D., SAS P., On the use of a wave based prediction technique for steady-state structural-acoustic radiation analysis
- Journal of Computer Modeling in Engineering & Sciences (CMES), 7 (2) (2005), 173-184.
- PLUYMERS B., VANMAELE C., DESMET W., VANDEPITTE D., Application of a hybrid finite element - Trefftz approach for acoustic analysis, Proceedings of the 10th International Conference on Numerical Methods for Continuum Mechanics & the 4th International Workshop on Trefftz methods, Zilina, Slovak Republic, 2005.
- DESMET W., PLUYMERS B., VANMAELE C., VANDEPITTE D., A review of the wave based prediction technique for efficient interior acoustic analysis, Proceedings of the 2005 Forum Acusticum, Budapest, Hungary, 2005, 151-160.
- PLUYMERS B., VANMAELE C., DESMET W., VANDEPITTE D., SAS P., A high performance hybrid finite element-wave based method for steady-state acoustic analysis, Proceedings of the Twelfth International Congress on Sound and Vibration (ICSV12), Lisbon, Portugal, 2005.
- PLUYMERS B., VANMAELE C., VANDEPITTE D., DESMET W., A Wave Based Method for the steady-state dynamic analysis of structural-acoustic problems, Proceedings of the International Congress on Noise and Vibration Emerging Methods (NOVEM2005), Saint-Raphael, France, 2005.
- DE CONINCK F., DESMET W., SAS P., Increasing the Accuracy of MDOF Road Reproduction Experiments: Experimental Validation, SAE NVC 2005, Traverse City, MI, 16-19/05/2005
- ZANARINI A., DE CONINCK F., MENDRO K., SAS P., Direct and Indirect Vibro-Acoustic Measurements for Road Noise NVH Predictions, IDETC/CIE 2005, ASME 2005 International Design Engineering Technical Conferences & Computers and Information in Engineering conference, Long Beach, CA, 24-28/09/2005

2.2.2 Scientific missions

- DAGA workschop "Fachausschuss Fahrzeugakustik" March 23, 2004, Strasbourg (France).
- DAGA workschop "Physikalische Akustik" September 16-18, 2004, Bad Honnef (Germany).
- NAG colloquium "actieve geluidscontrole" May 26, 2004, Utrecht (the Netherlands)
- Dialogue with CEN: establishing the framework for a CEN/Technical Report on typical vibration measures for typical applications for certain types of non-road vehicles.
- Machinery Directive (98/37/CE) standing committee: subject: Vibration "limits" into standards.
- 9 Meetings with CECE (Committee for European Construction Equipment) and FEM (European federation of handling Industries) regarding the advise for the directive on outdoor noise (2000/14/CE)
- 6 Meetings with the European Commission DG Environment and DG Enterprise and Industry on the advise for the directive on outdoor noise (2000/14/CE)
- VDI conference "Schwingungen in Verarbeitungsmaschinen", April 26-27, 2005, Leonberg (Germany)
- DAGA conference March 14-17, 2005, Muenchen (Germany).
- INCE Symposium, Managing uncertainties in noise measurements and predictions, ENSIM, ISMANS, 26-29 June, 2005, Le Mans (France)
- DEGA workschop "Fachausschuss Fahrzeugakustik" September 21-22, 2005, Zwickau (Germany).

2.2.3 Expected results

The status and the future planning of the research tasks are:

1. The research of the acoustical characterisation will be continued after the project. The aim is the improvement of the accuracy by applying an improved calibration procedure and an extension of the measurement range with respect to the current standards. After that, the improved impedance measurement method will be used to characterise porous materials.
2. The research of active noise control will be continued, particularly the development of improved actuators, control algorithms and new industrial applications.
3. Concerning active bearings, the state of the art has been investigated. At this moment, this research will be suspended.
4. The research and service for accelerated durability and comfort tests will be continued.

3 Workpackage 2: Lifecycle environmental aspects

3.1 Description of research works

3.1.1 Context

Over the last few years, product-oriented environmental legislation and standardisation have become important policy options. Important legislative actions within the EU include, for example, the Directives 2002/95/EC, 2002/96/EC and 2003/108/EC on electrical and electronic equipment (EEE), Directive 2000/53/EC on end-of-life vehicles, the Green book on Integrated Product Policy (IPP), and the draft Directive on establishing a framework for the setting of Eco-design requirements for Energy-Using Products (EuP).
Despite of the far-reaching consequences of these legislative actions, a chasm is recognised between the opportunities and barriers present and/or recognised in respectively industry, legislative bodies and research centres

3.1.2 Targets

The main objective of WP2 is to cross the identified chasm in a number of ways :
1. by informing industry by promoting standardisation and technical regulation (Task 2.1),
2. by performing a number of LCA projects with industry and by transferring general eco-design knowledge as well as the research results to industry (Task 2.2),
3. by participating and/or following up relevant standardisation commissions and of legislative actions (Task 2.3),
4. by creating a dialogue between industrial experts, universities and WTCM/CRIF (Task 2.4).

3.1.3 Scientific method and results

The activities performed in the framework of Work Package 2 can be classified into three broad categories: gathering of knowledge, creation of knowledge, and dissemination of knowledge. The activities are grouped into four tasks, as described below.

3.1.3.1 **Task 2.1. Inform industry**

In order to inform industry about the ongoing legislative actions, a thorough survey of the current legislative and standardisation activities has been performed. Both general overviews as well as clarifications of individual legislation/standardisation issues have been made, and are continuously updated. Particular attention has been paid to the developments regarding the EuP Directive.
In order to inform industry, a first session with members of the user committee was organised on November 4th, 2004 in Brussels (See also Task 2.4). Secondly, a seminar on Life Cycle Engineering was organised on February 24th, 2005 in Leuven. In order to create a wide dissemination platform, the seminar was organised in cooperation with Leuven Inc., WTCM, GOM Vlaams-Brabant and GOM Limburg. Speakers active in the CHASM project included Joost Duflou (CIB), Stephan Belaen (WTCM) and Walter Auwers (WTCM) (See announcement in Annex). A third dissemination activity was organised in Brussels on September 12, 2005, and was particularly aimed at informing SMEs. The workshop was an initiative of the CHASM project partners in cooperation with Agoria and the Ecodesign Awareness Raising Campaign of the German Fraunhofer Institute. (See announcement in Annex). Ca. 50 delegates from industry

participated in this event. Speakers from the CHASM project team included Stephan Belaen (WTCM) and Wim Dewulf (CIB).
In conjunction with the latter workshop, a number of ecodesign related articles were published in the Agoria Techniline newsletter, which has been sent to more than 8000 Belgian companies (e.g. W. DEWULF, Duurzame bedrijfsvoering: een winstgevend paradigma, Agoria OnLine, 7 september 2005.)
Finally, more continual access to LCE related information was provided through the CHASM website. Next to information on standardisation and legislation, an overview of guidelines and examples was also included in order to provide a valuable source of eco-design related information for machine designers.

3.1.3.2 **Task 2.2. Research and transfer of the results to industry**

In order to develop information needed for standard developers with respect to the environmental aspects of a machine's life cycle, a number of parametric Life Cycle Analysis (LCA) studies are conducted in order to evaluate the potential environmental impacts of a number of typical machine systems.

Particular attention was paid to the analysis of milling machines and laser machines.
A screening LCA of a typical milling machine reveals that the environmental impact of the electricity consumption is the dominant factor of the machine lifetime (Figure 1).

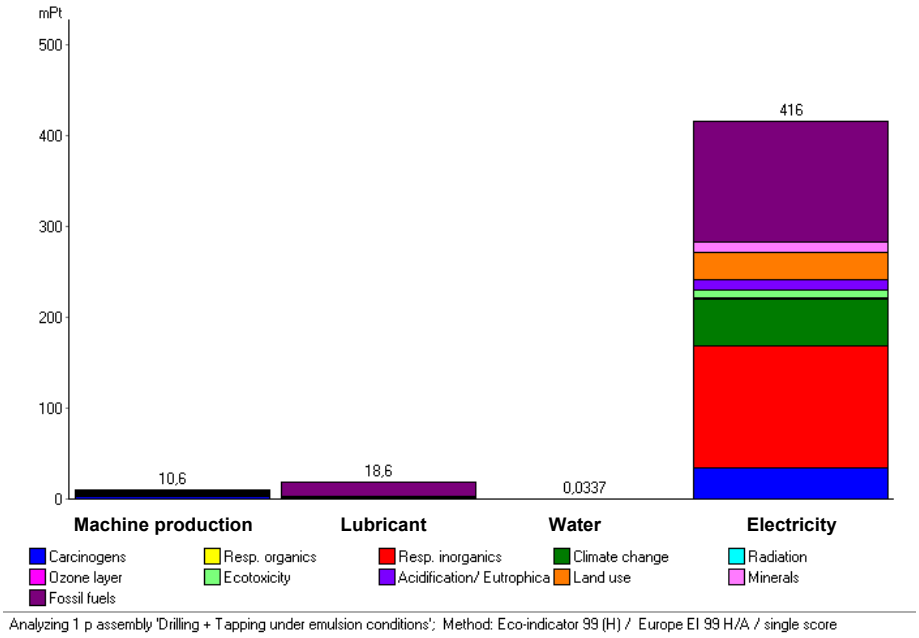


Figure 1: Screening LCA of a milling machine

In order to gain an overview of the main electricity losses of milling machines, a measurement campaign was initiated on a typical milling machine.
It appears that four start-up levels need to be crossed before the actual milling process can start. The final start-up level, causes an energy consumption of more than 1.5kW. Figure 2 and Table 1 show that the hydraulic pump (for cooling and lubrication) and the frequency converters are responsible for more than 75% of the total start-up energy.

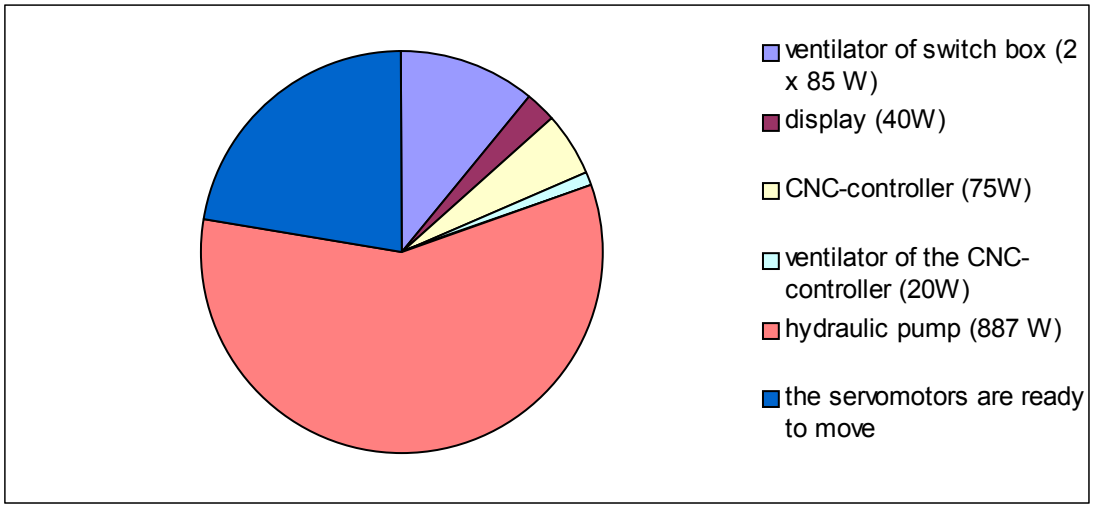


Figure 2: Contribution of milling machine subsystems to the overall energy consumption during stand-by

A more intelligent control, combined with more efficient components and power-down features could drastically reduce the overall environmental impact of the machine.
The in-use energy consumption was further scrutinised at different speeds (Figure 3) and load levels (Figure 4). The figures clearly show that even at higher speeds and loads, the contribution of the auxiliary systems remains significant. However, also with respect to the spindle, sigificant inefficiencies could be recognised (Figure 5).

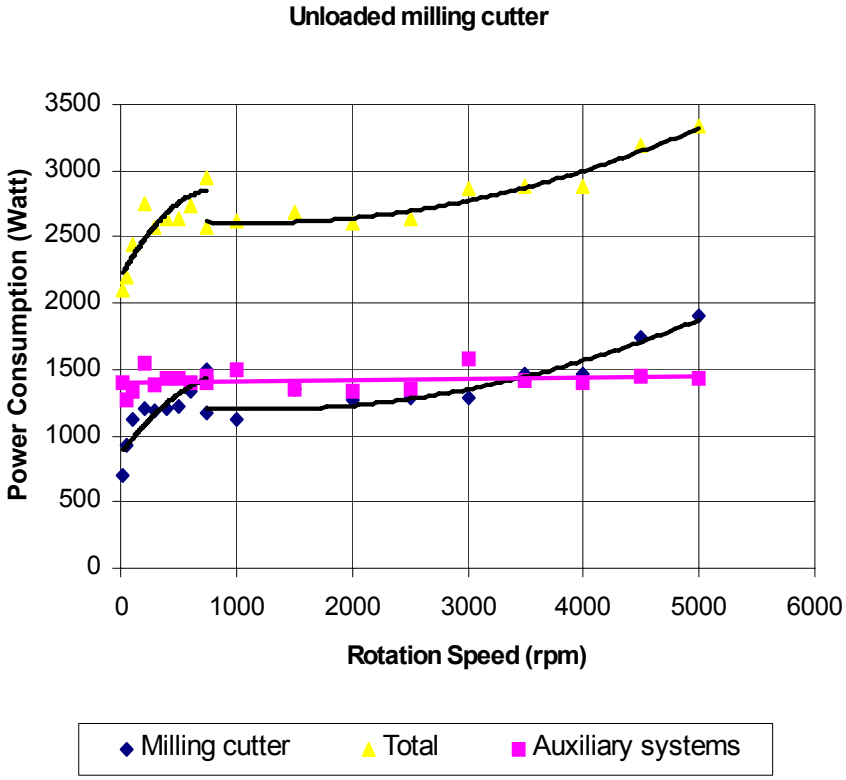


Figure 3: Evolution of the electricity consumption of the main spindle (milling cutter) and of the total machine as a function of the main spindle speed

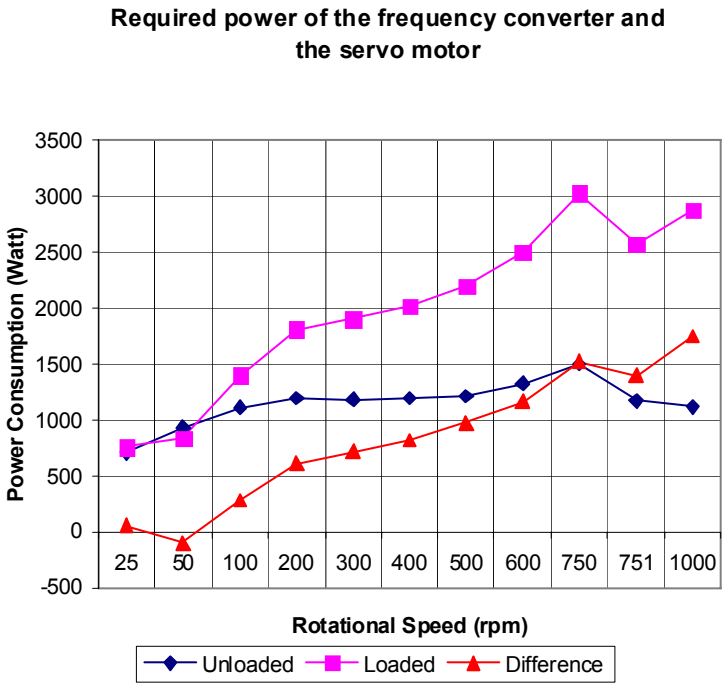


Figure 4: Evolution of the electricity consumption of the main spindle as a function of the main spindle load

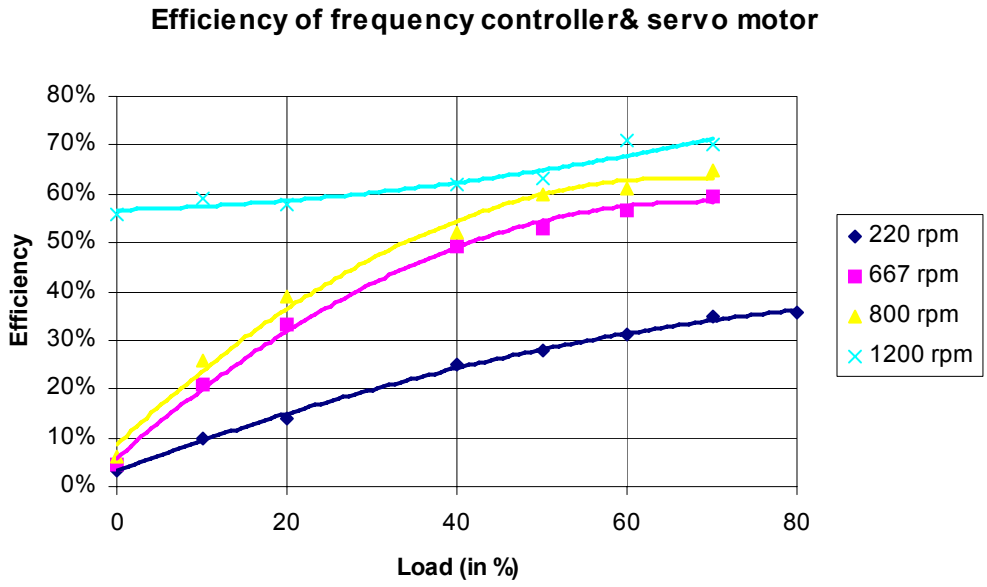


Figure 5: Evolution of the main spindle efficiency as a function of speed and load

For laser machines, the environmental impact of different machine architectures has been investigated using a screening LCA approach. The study reveals that flying optics laser cutting machines are, from an environmental point of view, superior to the fixed head machines due to the limited mass of the subsystems to be positioned. Due to the divergence of the laser beam in flying optics machines, a part of this energetic gain is however counteracted.

For the positioning systems, a number of configurations were analysed. The environmental impact caused by the energy consumption during use proved again to be dominant. A parametric screening LCA for drive systems was subsequently derived:

$$E_{tot} = \frac{M \cdot (A \cdot D + \eta_{drive} \cdot (V^2 - A \cdot D))}{2 \cdot \eta_{motor} \cdot \eta_{drive}}$$ where M represents the mass of the system to be positioned, A, V and D are the requested acceleration, maximum velocity and distance, and η the efficiency of respectively motor and drive. The study has lead to the quantification of efficiency ranges for common linear positioning systems.

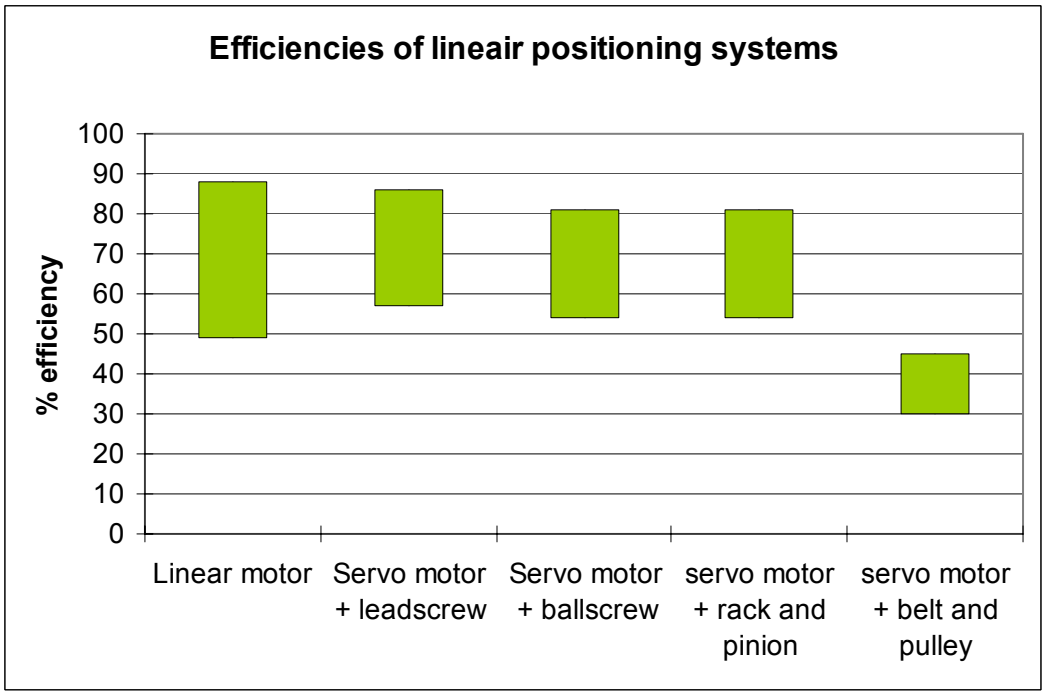


Figure 6: Efficiency ranges for common linear positioning systems

Based on the results of the performed LCAs, a number of six key environmental performance indicators (EPIs) have been defined for expressing environmental impact of machines and machine system components:

- *Cradle-to-gate material index [EI99 pts]:* This indicator expresses the overall cradle-to-gate environmental impact of the materials present in the machine or machine component. Environmental impact of manufacturing steps other than material production are not included, since LCA studies have shown their impact being often marginal.
- *Amount of material from suppliers lacking an Environmental Management System [kg]:* Despite of their relatively low impact in comparison to material production, it is important to monitor the efforts paid towards clean production. Therefore, the related environmental impact is expressed by referring to the absence of Environmental Management Systems.
- *Amount of restricted materials [kg]:* This indicator monitors the amount of materials, present in the machine or component, that are restricted due to legislative actions or company decisions.
- *Amount of non-inventoried materials [kg]*: This indicator expresses the quality of the first three indicators, since a high amount of non-inventoried materials might hide the presence of badly scoring materials.
- *Total energy consumption [kWh/functional unit]:* This indicator monitors the overall energy consumption of the machine (component) for performing a predefined task.

- *Lack of lifetime optimisation [%]:* This indicator expresses the difference between the technical machine (component) lifetime and the environmentally optimal lifetime. Indeed, due to wear-out of existing products and due to technological evolution of new products, a time span exists after which it is better to replace a component instead of further prolonging its lifetime.

The latter indicator requires the availability of a formula to calculate the environmentally optimal lifetime. The deduction of this formula for selected cases has been performed and is described in our publication "The environmentally optimised lifetime: a crucial concept in life cycle engineering".

3.1.3.3 **Task 2.3. Participate in an/or follow-up of standardisation activities**

In follow-up of the state-of-the-art survey performed under Task 2.1, the developments in the field are continuously screened, especially with respect to EU legislation, as well as ISO and CEN standardisation.
In the framework of the CHASM project, Wim Dewulf (K.U.Leuven) has registered as an expert in the CEN Environmental Helpdesk and the SETAC/UNEP Life Cycle Initiative while membership for the BEC mirror committee of the CENELEC CLC/TC ENV committee and for the BIN B031 committee mirroring ISO TC 207 has been applied for. Stephan Belaen (WTCM) continued his participation in the European debate on Integrated Product Policy (IPP).

Moreover, we actively participated in meetings and seminars on LCA and legislation (OVAM) and on research and standardisation (CEN).
We participated actively on the demand of industry on the on-going work with the proposal of a directive regarding Eco-Design for Energy Using Products (EUP). Many meetings were held with the European Commission DG Enterprise and The Belgian Government.

3.1.3.4 **Task 2.4. Dialogue between industrial experts, the university and WTCM/CRIF**

The events organised in the framework of Task 2.1 are exploited in view of fostering the dialogue between industry, academics and WTCM/CRIF. In particular, during the November 2004 user committee meeting, the industrial participants were invited to share their vision on the needs of the Belgian industry with respect to the EuP directive. Important points are:

- a general interest in Life Cycle Costing techniques. These techniques can support translate the advantages of more eco-design to the top management, since eco-design of EuP often results in a reduced life cycle cost.
- the need for timely information when work on implementing measures is starting.
- (pre-)normative research on defining use scenarios in view of the key EPI on energy consumption.
- the definition of the optimal lifetime as an EPI seems interesting, if it can be made more transparent.
- possibilities of in-use testing for monitoring the evolution of energy consumption or emissions.
- the effects of the changeover from thermostat-based to microprocessor-based control in the heating sector.

The results of the roundtable were shared with a number of Belgian companies in order to assess the representativeness of the conclusions.

In order to provide a reliable overview of the state of the art of life cycle engineering in current Belgian industrial practice, the project team decided to participate in the organisation of a

worldwide survey. To this aim, a 7 page questionnaire was sent to 300 Belgian companies. Similar data collection efforts were done in other countries by other university institutions, in particular in Australia, Germany, Austria, Signapore, Taiwan and the USA. For Belgium, 25 companies returned the filled out questionaire. Although this number is not suffient to draw statistically relevant conclusions on the penetration and status of ecodesign in the Belgian industry, the combined results of the studies worldwide allowed some very relevant conclusions, which were presented on June 2nd, 2006 in Leuven by the worldwide coordinator of the survey, Prof. Hartmut Kaebernick (H. KAEBERNICK, S. KARA, Environmentally Sustainable Manufacturing: A Survey of Industry Practices, in: J. DUFLOU et al., Proc. Of LCE2006, May 31st - June 2nd, 2006, Leuven, pp.19-28). Worldwide, the majority of companies acknowledge the importance of environmental requirements, although different paths of implementation with different priorities are found in different continents. Whereas few Asian or Australian companies make use of dedicated life cycle engineering tools, American companies clearly focus on the life cycle costing tools, while in Europe more attention goes to Life Cycle Assessment and Design for Recycling tools. Moreover, Europe is clearly focussing on collection and material recovery - which can be traced to the European directives on e.g. WEEE, ELV,... - while the USA is focussing on remanufacturing as a business opportunity and the Asia-Pacific region focusses on cleaner production techniques. Worldwide, ecodesign related legislation was seen to have negative effects on production costs, but positive effects on new product development and business opportunities.

3.2 Network working, users committee

A user committee meeting was organised at the premises of WTCM and was attended by Dimitri Harmegnies (FOD Wetenschapsbeleid), Stephan Belaen (WTCM), Joost Duflou (K.U.Leuven), Wim Dewulf (K.U.Leuven), Wouter Lowet (K.U.Leuven), Barbara Willems (K.U.Leuven), Piet Fordel (Atlas Copco), Els Baert (Daikin), Herman Ulens (ACV). The conclusions of the meeting were communicated to a larger interested public, including Didier Bomal (Saintrochcouvin), Luc Vangheluwe (Van De Wiele), Kris Vanderhallen (Continental Energy Systems), Chris Grammens (Reznor), Felix Vaneyken (Agoria), Walter Auwers (WTCM)

3.3 Diffusion and valorisation

3.3.1 Publications

- J.R. DUFLOU, W. DEWULF, Eco-impact anticipation by parametric screening of machine system components, Proc. of the Advanced Summer Institute on Product Engineering: Eco-Design, Technology and Green Energy, Brasov, 14-21 July 2004, 19-27.
- W. DEWULF, J.R. DUFLOU, The environmentally optimised lifetime: a crucial concept in life cycle engineering, Proceedings of First Global Seminar on Life Cycle Engineering, Berlin, September 2004.
- J.R. DUFLOU, W. DEWULF, Eco-impact anticipation by parametric screening of machine system components, Product Engineering: Eco-Design, Technology and Green Energy, Springer Verlag, Berlin, 2005.
- Belgian viewpoint , on industries position regarding the Proposal for a framework directive on eco-design for energy using products.
- W. DEWULF, Duurzame bedrijfsvoering: een winstgevend paradigma, Agoria OnLine, 7 september 2005.

- T. Devoldere, W. Dewulf, B. Willems, J.R. Duflou, The Eco-Efficiency of Reuse Centres Critically Explored- The Washing Machine Case, Proceedings of the 13th CIRP International Conference on Life Cycle Engineering, 31 May - 2 June, 2006.

Website
http://www.kuleuven.ac.be/cib/chasm

3.3.2 Scientific missions

- OVAM Studiedag "Gebruik en misbruik van LCA's in het milieubeleid", 09.09.2003 (Wim Dewulf)
- CEN Maxiquest Workshop on Research and Standards, 11.09.2003 (Wim Dewulf, S. Belaen)
- Meetings with with the European Commission DG Enterprise and The Belgian Government regarding the Commissions proposal for a framework directive for eco-design for energy-using products (S. Belaen).
- Meetings regarding Eco-design with the "Federale Raad voor Duurzame Ontwikkeling" (S. Belaen)
- Agoria Studiedag "Machine Solution Provider" (Joost Duflou)
- Advanced Summer Institute on Product Engineering: Eco-Design, Technology and Green Energy, Brasov, 14-21 July 2004 (W. Dewulf, J. Duflou)
- First Global Seminar on Life Cycle Engineering, Berlin, September 2004 (J. Duflou)
- Green Chemistry Course, Ghent University, November 2004 (J. Duflou)
- 11th International CIRP Life Cycle Engineering Seminar, Belgrade, June 20-22, 2004 (J. Duflou).
- 12th International CIRP Life Cycle Engineering Seminar, Grenoble, April 3-5, 2005 (W. Dewulf, J. Duflou).
- Workshop Integrating environmental aspects into European standardisation, Brussels, December 2, 2005 (W. Dewulf)
- Workshop promoting eco-design activities to the SMEs of the electrical/electronics sector, December 5, 2005 (W. Dewulf)

4 Workpackage 3: Emissions of engines

4.1 Description of research works

4.1.1 Context

Air pollution is worldwide recognised as a very big issue. For this reason, many strict EU directives have come into force in the last decade. Every manufacturer has to fulfil these directives before their products are allowed to be launched on the market. A broad range of techniques is developed to fulfil these regulations. Many of these directives are reviewed and new directives are developed at a high rate. Besides that, these directives are very detailed. A lack of communication between industries, research centres, government... is noticed. This results in a shortage of up to date information in these institutes, especially at the industries. Technological solutions are asked to fulfil the new directives and also the new standards. Research centres and universities are also hardly involved in the development of these directives and standards. However, the directives and standards are very important because they determine how the product will be made and what they will look like.

4.1.2 Objectives

The European Commission develops new strict regulations in the field of emissions of engines. New technologies, which are the means to fulfil the regulations, will be followed up mainly in engine design (injection, engine control, EGR...), in fuel and oil technologies and exhaust gas aftertreatment (lean NO_x, SCR, particulate traps...). Particularly in the field of vehicles powered by diesel engines (both light vehicles and heavy duty vehicles), new technologies are necessary to meet the future regulations.

According to the European Commission, natural gas, hydrogen and biofuels have to replace 20% of the conventional fuels in 2020. The research will be focussed on the use of alternative gaseous fuels like natural gas, LPG and hydrogen and a comparison will be made with gasoline and diesel.

Legislation on non-road mobile machinery is at this moment not as developed as legislation on road vehicles and those emissions constitute a significant part of the total man-made emissions. For this reason, the possibility of implementing technologies developed for road vehicles on non-road vehicles will be researched with the intention to reduce emissions drastically and to propose realistic emission (target) values.

Industries and users are not always informed thoroughly of those new directives, standards and technologies. Therefore, there will be attempted to supply these instances with information in the form of a seminar, documents and/or a website.

4.1.3 Scientific method and obtained results

- A workshop on "standards and research" was attended (Maxiquest: Maximising Quality and Efficiency of Standards through Normative Research), organised by CEN. At this workshop the emphasis was on the importance of an interaction between standards and research. In other words, how can the development of standards contribute to a more result oriented research programme and vice versa.

- The literature study on new technologies for passenger cars engines, which have the aim to reduce harmful emissions of engines, has been round off. The last year, the focus was on emission reduction technologies. Books, specialized magazines, courses and the internet served as sources for information. The full, finalised text is attached (annex 1, in Dutch). Of course, these technologies evolve very quickly; therefore, it is necessary that the text will have to be adapted frequently to keep it up to date.

  The table of contents of the final text is summed up here:

1. Introduction and background
    - 1.1 Strict emission regulations
    - 1.2 Reduction CO_2 emissions
    - 1.3 Increasing mass and power of new cars

2. Engines
    - 2.1 Spark ignition engines
        - 2.1.1 Variable valve train
        - 2.1.2 Direct injection
        - 2.1.3 Downsizing
    - 2.2 Diesel engines
        - 2.2.1 Injection systems
        - 2.2.2 Charging
        - 2.2.3 Emission reduction
    - 2.3 Special cycles
        - 2.3.1 Miller/Atkinson cycle
        - 2.3.2 Auto-ignited premixed combustion

3. Exhaust gas aftertreatment
    - 3.1 Three way catalyst
    - 3.2 Diesel oxidation catalyst
    - 3.3 Particulate filter
    - 3.4 NO_x-reduction in lean mixtures
        - 3.2.1 NO_x trap
        - 3.2.2 Lean-NO_x catalyst

- A document on new emission reduction technologies for heavy-duty vehicles and non-road machinery is made. Both engine design (common rail, VNT, EGR...) and exhaust gas after-treatment (SCR, NO_x trap, particulate traps...) are revised. In order to understand the working principle of these technologies an introduction of the formation of harmful exhaust components is given. This text served also as a basis for the presentation at the workshop (see below). The text, with the title "New emission reduction technologies for high speed diesel engines" is in Dutch and can be found in annex 2. The table of contents is summed up here:

1. Introduction
    - 1.1. Basic principles of diesel combustion

2. Formation of harmful exhaust gas components
    - 2.1. NO_x
    - 2.2. Particulates
    - 2.3. Hydrocarbons
    - 2.4. CO
    - 2.5. SO_2

3. Engine design for emission reduction
    - 3.1. Injection technology
    - 3.2. Breathing
    - 3.3. EGR
    - 3.4. Premixed combustion with compression ignition
    - 3.5. Miller-cycle

4. Exhaust gas aftertreatment
    - 4.1. Oxidation catalyst
    - 4.2. Particulate filter
    - 4.3. Selective Catalytic Reduction (SCR)
    - 4.4. NO_x trap en lean-NO_x catalyst

- Another issue is the use of alternative gaseous fuels to reduce harmful emission levels. The Laboratory for Transport Technology has about 15 years of experience with LPG, natural gas and hydrogen as a fuel for engines. The previous academic year, experiments were conducted on a new test rig, based on an Audi single cylinder prototype engine. The emphasis of the research is on hydrogen. A report (in English) is written about the use of hydrogen in internal combustion engines. This work describes the possibilities, the advantages and the drawbacks of hydrogen engines. The text can be found in annex 3.

- Experimental research is done on the possibilities of EGR on hydrogen fuelled engines. EGR offers the possibility to reduce the NO_x emission level, which is the only harmful exhaust gas of hydrogen engines, drastically. EGR is the abbreviation of Exhaust Gas Recirculation and its basic idea is very simple: a part of the exhaust gases is conducted back to the inlet duct and mixes there with fresh air. This technique is already used for several years in gasoline and diesel engines. For gasoline engines this technology offers a betters efficiency because less air has to be throttled (less pressure losses). In contrast with this gasoline engine a diesel engine and hydrogen engine do not use a throttle to control the power, it just adapts the amount of fuel injected. This is possible because those engines can run on a lean ('more air then fuel') mixture. That is the main reason why a diesel and a hydrogen engine have a better part load efficiency. Therefore, the advantage of EGR is not the better fuel economy but cleaner emissions. The inert (already burnt) exhaust gas replaces the surplus of air and lowers the combustion temperature. As a result, NO_x emissions will be lower because NO_x production is very dependent on temperature.

  The tests are done on a one-cylinder CFR research engine. This engine has two valves, a fixed engine speed of 600 rpm, an adjustable compression ratio and a swept volume of 612 cm^3. It is equipped with a cooled EGR-system, a cylinder pressure transducer and the necessary temperature and pressure sensors. A report and results of these tests can be found in annex 4.

  During 2005 more tests were carried out on the Audi and CFR engines. Results are presented in several papers (see annex 10: accepted papers for congresses in 2006).

- Other work on alternative fuels is the *Hythane*® bus project. Hythane is a registered trademark of Hydrogen Consultants Inc. and is a mixture of natural gas and hydrogen (15-20% vol.). The aim of the project was to change an existing natural gas bus to a bus that can run on *Hythane* and to compare the two fuels. The engine was adapted and for preparation tested on an engine dynamometer. With *Hythane* as a fuel, the engine had a lot of torque at low speeds (800 – 1500 rpm) and reached a maximum power output of 143 kW. Results that are more interesting were obtained when the bus was tested on a chassis dynamometer. The

comparison between natural gas and *Hythane* was very advantageous for the latest. Under the given test conditions pollutant emissions and greenhouse gas emissions were reduced quite drastically especially when considering the rather low portion of hydrogen in the fuel (only 20% vol.). All details are described in the document in annex 5.

- Within the scope of informing the industries and the users, an article on internal combustion engines on hydrogen was written for the Committee for European Construction Equipment (CECE). This article will be published in the magazine 'Construction Europe'. Annex 6 contains a copy of this article.

- As a result of the meeting with the partners of the users committee (see paragraph 'Activity of the network, users committee) a report is made of the problems that the non-road sector faces now or will face in the future. New, tight emission regulations will come into force and pressure on relatively small vehicle manufacturers is becoming high. Clear problems are the lacking of test facilities of these companies, which will be necessary in the future, and the certification procedure of engines for new vehicles. This report can be found in annex 7.

- Within the scope of informing the industries and the users, a workshop was organised. All partners and other interested persons were invited to attend a workshop with the following subject: 'Emission of gaseous and particulate pollutants from internal combustion engines'. The workshop, which was attained by about 30 people, was held the 22nd of April 2005 at the Department of Mechanics of Flow, Heat and Combustion at Ghent University. Five presentations were given with afterwards a panel discussion. The presentations were made by the partners of the project and had the following subjects (originally in Dutch):

    - "New emission regulation of diesel engines for non-road vehicles", by Mr. Stephan Belaen (WTCM)
    - "Built-in of diesel engines in mobile machines in the framework of directive 2004/26/EC" by Mr. Antoon Vermeulen (CNH)
    - "Emission directives and technologies for medium speed diesel engines", by Mr. Tim Berckmoes (ABC)
    - "New emission technologies for high speed diesel engines", by Mr. Stefaan Verstraeten (UGent)
    - "Alternative gaseous fuels for internal combustion engines", by Prof. Roger Sierens

  The workshop programme, the presentations and the attendance list can be found in annex 8.

4.2 Activity of the network, users committee

A meeting was held the 26th of March 2004 at the Laboratory for Transport Technology (UGent) with the attendance of the project co-ordinator Stephan Belaen and the following partners of the users committee:

Antoon Vermeulen, Case New Holland
Kris Van der Hallen, CES
Tim Berckmoes, Anglo Belgian Corporation

and the project worker and co-workers:

Stefaan Verstraeten, UGent
Roger Sierens, UGent
Sebastian Verhelst, UGent

A very useful discussion led to some interesting remarks and problems that are described in the report of the meeting.

4.3 Diffusion and valorisation

4.3.1 Reports

- New developments for passenger car engines (in Dutch) (57 p)
- New emission technologies for high speed diesel engines (in Dutch) (34 p)
- Hydrogen as a fuel for internal combustion engines (9 p)
- EGR and lean combustion strategies for hydrogen fuelled combustion engines (11p)
- Tests on a CNG – Hythane bus (in Dutch) (12 p)
- Internal combustion engines on hydrogen (CECE paper) (2p)
- Problems for the non-road sector (in Dutch) (10 p)
- Workshop programme, presentations and attendance list (5 + 8 + 6 + 7 + 7 + 10 p)
- Report of the CHASM meeting (in Dutch) (2 p)

4.3.2 Publications (of the research group):

- "Utilisation of hydrogen in transportation systems", Sierens R. and Verhelst S., International Workshop on Hydrogen Energy, New Delhi, India, 11-13 December 2003
- Poster: "Simulation of the power cycle of hydrogen fuelled SI engines", Verhelst S. and Sierens R., Combura Symposium, Nieuwegein, Netherlands, 3 March 2004
- "Hydrogen fuelled SI engines: experimental results" + poster session: "Simulation of the power cycle of hydrogen fuelled SI engines", Verhelst S. and Sierens R., Lean Combustion Technology Conference, Tomar, Portugal, 25-29 April 2004
- "Development of a single cylinder IC engine for hydrogen", Verstraeten S., Sierens R. and Verhelst S., 7th International Student Scientific Association Conference, Lublin, 13-14 May 2004
- "The laminar burning velocity of mixtures of hydrogen, air and residuals at engine-like conditions", Verhelst S., Sierens R., 18e Journées d'Etudes, Louvain-la-Neuve, May 2004
- "Utilisation of hydrogen as a fuel for internal combustion engines in road transportation systems", Sierens R. and Verhelst S., HTM International Conference, Donetsk, Ukraine, 17-21 May 2004
- "A high speed single cylinder hydrogen fuelled internal combustion engine", Verstraeten S., Sierens R. and Verhelst S., FISITA World Automotive Student Congress, Barcelona, 23-27 May 2004
- "The laminar burning velocity of mixtures of hydrogen, air and residuals at spark-ignition engine conditions", Verhelst S. and Sierens R., FISITA World Automotive Congress, Barcelona, 23-27 May 2004
- "Laminar burning velocities of mixtures of hydrogen, air and residuals at spark-ignition engine conditions", Verhelst S. and Sierens R., 15th World Hydrogen Energy Conference, Yokohama, Japan, June 2004
- "Alternative fuels and engine technology", Sierens R., CECE Congress 2004, Stockholm, 18 June 2004

- "The laminar burning velocity and Markstein lengths of hydrogen-air mixtures at engine-like conditions", Verhelst S., Woolley R., Lawes M. and Sierens R., 30th International Symposium on Combustion, Chicago, US, July 2004
- "Development of a hydrogen fuelled single cylinder engine", Verstraeten S., Verhelst S. and Sierens R., 10th International Congress CONAT, Brasov, 20-22 October 2004
- "Hydrogen fuelled internal combustion engines", Sierens R. and Verhelst S., International Conference on Automotive Technology, Istanbul, 26 November 2004
- "Combustion strategies for hydrogen fuelled IC engines", Verstraeten S., Verhelst S., Sierens R., HYPOTHESIS VI symposium, Havana, 8-12 May 2005
- "EGR and lean combustion strategies for a single cylinder hydrogen fuelled IC engine", Sierens R., Verhelst S. and Verstraeten S., EAEC European Automotive Congress, Belgrado, 30 May –1 June 2005
- "An overview of hydrogen fuelled internal combustion engines", Sierens R., Verhelst S. and Verstraeten S., International Hydrogen Energy Congress & Exhibition, Istanbul, 13 –15 July 2005.

Accepted:

- "A comprehensive overview of hydrogen engine design features" Verhelst S., Verstraeten S., Sierens R. Procedings of the IMech E, part D, Journal of Automobile Engineering
- "A critical review of experimental research on hydrogen fuelled SI engines". Verhelst S., Verstraeten S., Sierens R. SAE paper 2006-01-0430, April 3 - 6, 2006, Detroit
- "Development of a simulation code for hydrogen fuelled SI engines". Verhelst S., Verstraeten S., Sierens R. ASME-ICED 2006 Spring Technical Conference, paper ICES 2006 - 1317, May 8-10, 2006,Aachen
- " A Comparison between lean burn operation and stoichiometric operation with EGR for a hydrogen fuelled IC engine". Verstraeten S.,Verhelst S., Sierens S. 16 th World Hydrogen Energy Congress, June 13-16, 2006, Lyon
- "Combustion strategies and NO_x emissions for hydrogen". Verhelst S.,Verstraeten S., Sierens S. FISITA 2006 Congress, October 22 - 27, 2006, Yokohama

4.3.3 Journeys and scientific conferences (of Mr. S. Verstraeten):

- Workshop on Standards and Research (Maxiquest-Norm)
- CEN Management Centre, Brussels, 11 September 2003
- Aim: An introduction to the use, the purpose, the possibilities and disadvantages of standards. Workshop about the interaction of standards and research.
- Symposium: Sustainable Mobility by Sustainable Energy
- Busworld, Expo Kortrijk, 20 & 21 October 2003
- Aim: To inform people about the use of alternative fuels like hydrogen and natural gas in buses: experiences, future projects, possibilities, disadvantages. To debate about sustainable mobility and to brainstorm about a concrete plan.
- Short course on Spark Ignition Engine Emissions
- The University of Leeds, UK, 17 – 21 November 2003
- Aims: To obtain more in depth knowledge of spark ignition engine combustion and emissions. Learn more about engine warm up, catalyst performance and warm up, fuel

composition influences, after-treatment technology, particulate emissions, leading edge technologies…

- Symposium Clean Technologies, cabinet of Minister Fientje Moerman, minister for Economy, Energy, Foreign Trade and Science Policy.
- Egmont Palace, Brussels, 2nd of February 2004
- Aim: To bring politicians, industry and research centres closer together en debate about future clean vehicle technologies (hybrids, CNG, hydrogen…), obstacles perceived by the market and public-private partnerships in order to remove the obstacles.
- 7th International Student Scientific Association Conference, Lublin, Poland, 13-14 May 2004
- Aim: Presenting paper "Development of a single cylinder IC engine for hydrogen"
- Travelling Fellowship of the FISITA World Automotive Congress, Barcelona, 17-27 May 2004
- Aim: Five days of visiting automotive companies and workshops together with 23 young engineers selected from all countries worldwide. Presenting the paper "A high speed single cylinder hydrogen fuelled internal combustion engine" at the student congress.
- 6th CHAPNET gas engine workshop, Brussels, 10 November 2004
- Aim: Discussion about new gas engine technologies and emission technologies
- Clean Cars 2010, organised by the European Federation for Transport and Environment, Brussels, 20 January 2005
- Aim: Discussion on EURO 5 emission standard for passenger cars and future CO_2 policies for passenger cars.
- HYPOTHESIS VI symposium, Havana, Cuba, 8-12 May 2005-06-15
- Aim: Presenting paper "Combustion strategies for hydrogen fuelled IC engines"

5 Workpackage 4: Health and safety aspects of machinery

5.1 Description of research works

5.1.1 Context

Since the last decade a lot of EU directives have come into force of which many apply to products (the "new approach" directives based on Article 95 of the EC Treaty) and to the health and safety of workers (the "social" directives based on Article 138 of the EC Treaty).
- Directive 98/37/CE: safety of machinery
- COM(2000)899 final: the revision of directive 98/37/CE
- Directive 89/655/CEE on the minimum safety and health requirements for the use of work equipment by workers at work
- The safety and environmental problem with electromagnetic fields in the human environment has led in Europe to the introduction of a so called Council Recommendation for Electromagnetic Fields- EMF (1999).

WTCM/CRIF is faced with the facts that:
- A lot of companies still have a lack of knowledge about the existing technical regulations and their related standards in the field of safety of machinery and safety aspects of EMF.
- There is not enough support towards industry from research centers and universities in this domain.
- As to future directives and standards the experts of research centers- and universities are not enough involved in the legislation and standardization process on safety for machinery and safety aspects of EMF.
- The research at the universities (technological and prenormative) is not always in line with the requirements of the future directives and standards

5.1.2 Targets

The main objective of the project is to contribute, both on active and passive way, on solving each of the above mentioned shortcomings within a well-chosen selection of directives (EMC- Electromagnetic Compatibility, v.s. EMF- Electromagnetic Fields in the Human Environment, the machinery directive and the project for a new machinery directive) and standardization (BEC- Belgian Electro technical Committee, CENELEC- European Electrotechnical Comission), CEN and ISO) activities. To solve these shortcomings the respective tasks within the project are:
- To inform industry by promoting standardization and technical regulation as a useful economic and social tool that has the potential to play a larger role in protecting the environment and the health and safety of workers on EMF.
- To transfer the knowledge and results of research towards more applicable EMF projects
- To participate in the standardization activities of the technical committees (EMC TC110, EMF TC 106, CEN/TC 114 and ISO/TC 199 on Safety of machinery and IEC/CENELEC/TC44X: Safety of machinery electrotechnical aspects

5.1.3 Scientific method and results

5.1.3.1 **EMF – Health and safety aspects**

The acronym EMF (Electromagnetic Fields in the Human Environment) is worldwide used to indicate the exposure of people to electromagnetic fields. These fields can be functional (e.g.

wireless telephone) or a not functional sub product such as a leak field of a PC (Personal Computer) screen or transformer. The frequency range of the EMF range is from 0 to 300 GHz and divided in 2 frequency regions namely low frequencies from 0 to 100 KHz and radio frequencies above 100 KHz. At low frequencies currents are induced in the human body and at higher frequencies thermal effects are dominant.

The project started with the study and follow-up of normalization activities around the outcome of standards under development. As a member of technical committee TC106 via BEC (Belgian Electro technical Committee) these activities are followed and all relevant documents are studied.

As a result of this study a list of all EMF related standards is made with comments for possible use in the future. This activity is included in the EMF guidance document
In this guidance document a table with a broad range of industrial, commercial and other applications related to the whole frequency range from 0 – 300 GHz is compiled.
In this table certain frequency ranges are related to applications and the limits, standards and measuring methodologies are studied.
This activity is done in close cooperation with the AGORIA EMF working group and achieved through several meetings. For practical implementation each application is explained through the use of an example in annex.
A study of cost effective measuring techniques and equipment practical usable in industry, work environment or other, is made to support the related standards.
A presentation (PowerPoint) is made at the end of the first year for dissemination of the project results

The 2nd year the follow-up and study of the normalization activities is continued as a member of TC106 via BEC (Belgian Electro technical Committee). The results of normalization activities and outcome of new standards is summarized and included in the EMF guidance document. This guidance document can be used by companies to fulfill the social directive relating Electro Magnetic Fields. (identification and appropriate measurement following EMF measurment standards)

All kind of products has been classified according to their frequency range. For each category, the type of industry or company was identified. Also indicators and all kind of means were added to catalog potential EMF relevance.

For industrial purposes working in the radio frequency domain, the frequencies are laid down in the ISM frequency ranges (CISPR rules). For measuring apparatus the following classification was made:
- Low frequency fields
- HF/RF microwave fields
- Personal protection applications

The document contains a table with the following data:
- Category of apparatus/application and their use
- Where the EMF phenomenon should be investigated
- Reference to applicable Standards
- Kind of measurement or simulations necessary and an indication of practical applicability

For each category there will be an annex describing the specific EMF problems. There will be information included for the product developer and for the user (including validation of the environment where there phenomena take place). A study of cost effective measuring techniques and equipment practical usable in industry, work environment or other, is made to support the related standards.

This activity is done in close cooperation with the AGORIA EMF working group and achieved through several meetings.

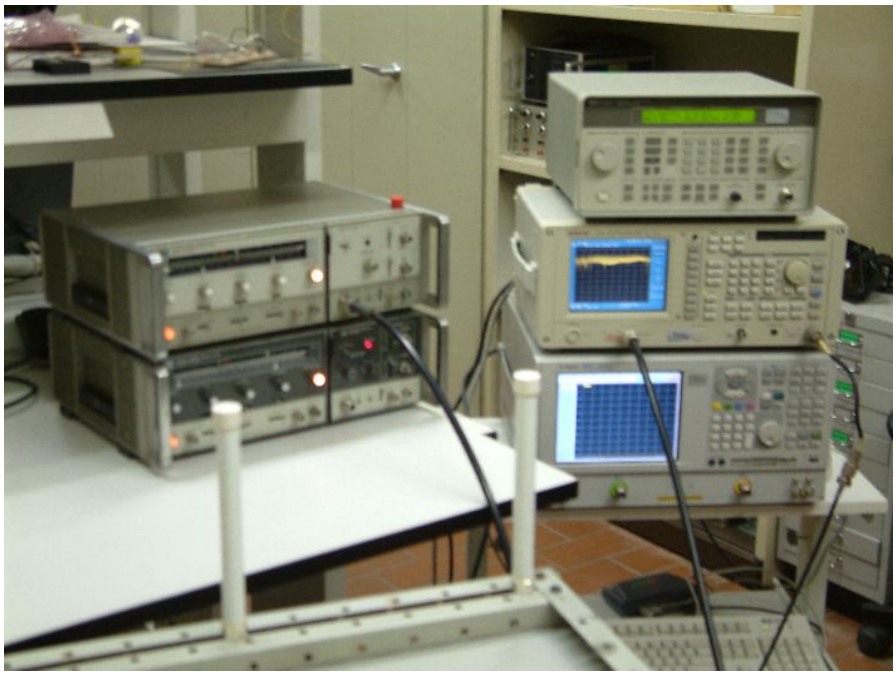
An abstract of results of the prenormative research on Electromagnetic Shielding for High Frequencies was made with the intention to use the results for shielding and screening also in the case of 'Personal Protection Equipment'), PPE's.
Activities within the AGORIA EMF working group and as a member of the TIS-EMC steering committee were continued

During the 3th year the follow-up and study of the normalization activities is continued as a member of TC106 via BEC. The results of normalization activities and outcome of new standards is summarized and included in the EMF guidance document
Abstract of results of the WTCM EMSHIFR (Electromagnetic Shielding for High Frequencies), prenormative research project was made with the intention to use the results for shielding and screening also in the case of 'Persoonlijke Beschermings Middelen), PBM's
Activities within the AGORIA EMF working group and as a member of the TIS-EMC (TIS 20500) steering committee were continued.
In this period the Guidance document 'Gids voor toepassing van de EMF richtlijn' was finalized.
Also a generic test object for demonstration purposes on Electromagnetic Interference operating in a broad frequency range is developed and tested.

Picture 1 showing the generic test object for interference measurement with 6 antennas

Picture 1

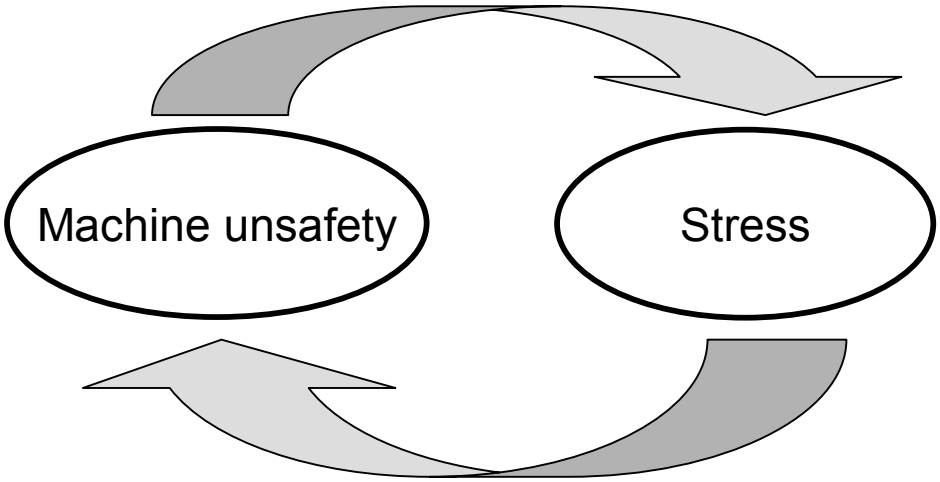
Picture 2 showing partial generic test antenna setup with associated equipment for interference demonstration



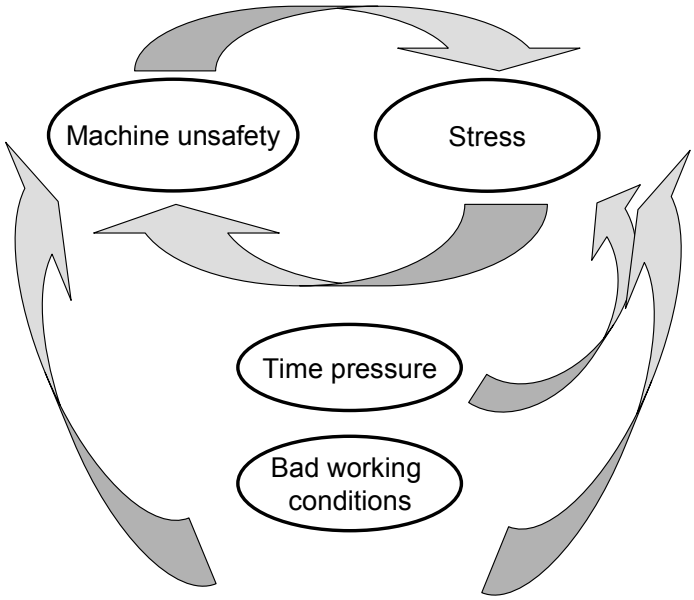
Picture 2

5.1.3.2 **Stress – Health and safety aspects**

The machinery directive (98/37/EC) and in particular its annex I, lays down the essential health and safety requirements relating to the design and construction of machinery and safety components.
Chapter 1.2.2 "Principles of safety integration" reads:
(…)
(d) Under the intended conditions of use, the discomfort, fatigue and psychological stress faced by the operator must be reduced to the minimum possible taking ergonomic principles into account.
(…)
A study has been made looking at the interrelation between stress and the operation of a machine. Unsafety and stress are clearly interrelated.



Unsafety leads to stress and vice-versa. Therefore, the machinery directive itself can already be considered as a comprehensive guideline on the prevention of stress. Besides unsafety, two major factors that cause stress can be easily identified. One is the almost permanent time pressure that characterises many work environments. The other is the ergonomic circumstances under which the work is being carried out, in many cases strongly related to the user interface of the operated machinery.



A report was made to get insight in the design aspect of machine with relation to psychological stress.

5.1.3.3 **Case study: Harvesting equipment**

Harvesting equipment is equipment which has both important safety aspects, as well mental workload related aspects. The harvesting is in many cases done by contractors. These are not farmers, but companies that offer the harvesting as a service to the farmers.
Harvesting is related to many stressing factors: due to the effect of seasonal and weather conditions on the harvesting, the time element is very important. In terms of ergonomics a dramatic improvement has taken place with respect to the work conditions in the cockpit of the harvesting machine. Nevertheless weather conditions during harvesting may make put an additional strain on the operator, in particular when things go wrong. After all, harvesting takes place in an environment which is not as structured and predictable as a factory shop floor. Breakdowns and malfunctions generate significant mental strain in such an 'unpredicatable' environment.
A report has been made. In the frame of this report, a manufacturer of harvesting equipment was interviewed as well as a harvesting contractor.

5.1.3.4 **safety-related considerations of electrical, electronic and programmable electronic control systems**

As a result of automation, demand for increased production and reduced operator physical effort, electrical control systems of machines play an increasing role in the achievement of overall machine safety. Furthermore the control systems themselves increasingly employ complex electronic technology. It will be important to set out an approach to safety-related considerations of electrical, electronic and programmable electronic control systems of machines and to provide requirements to achieve the necessary performance.

This very complex material is for the moment being standardised. An in depth study has been started to learn more about these standards.

5.1.4 Preliminary conclusions and recommendations

The research work in the second period of the project was directly related to the impact of the published EMF Directive in june 2004Waited results and calendar
The development by the standardization organizations of standards related to EMF (TC106) will be closely followed. The guidance document will be finalized (all annexes). Also a study based on WTCM research activities will be done related to shielding and applicable for "Personnel Protection Equipment (PPE).

The study on "Stress – Health and safety aspects" will be concluded by a report that will be a practical guide (maybe CEN Technical Report) for manufacturers of machinery.

The study on "safety-related considerations of electrical, electronic and programmable electronic control systems" will be concluded by a report that will be a practical guide (maybe CEN Technical Report) for manufacturers of machinery.

5.1.4.1 **References**

A list of all IEC-CENELEC-BEC standards and documents is updated and included in the EMF guidance document

A project presentation with research progress of the 2nd year is updated

5.2 Network working, users committee

The activities on networking in the 2nd project period were again mainly dedicated to expand existing contacts with industrial partners and AGORIA. The collaboration with AGORIA was with 2 departments, namely the social department which feels a further need for the implementation of the EMF directive, and the electric and electronics department in the field of standardization.
To form a user committee a part of the related activities in the steering committee of the AGORIA TIS-EMC project: "Stimulering van EMC bewustzijn en technologische oplossingen" was used. A list of members is included in annex..

5.3 Diffusion and valorization

5.3.1 Publications

- EMF document: Guide for the implementation of the EMF directive in industry (version 4 by L. Somers and S. Belaen)

- Project TAP – CHASM Power-Point presentation preparation giving an overview of the project with more specific detail of the activities carried out in WP5 – EMF.

- Belgian viewpoint , on industries position regarding the Proposal for new Machinery Directive

5.3.2 Scientific missions

- 3 Meetings with DG Enterprise of the European Commission to participate in the legislative work regarding safety aspects for the new machinery directive

- 10 Meetings with Orgalime (the European association of the mechanical and electrical engineering industry) regarding safety aspects for the new machinery directive.

- 4 meetings with the Federal Public Service Economy SME's, Self-Employed and Energy

6 Workpackage 5: Electromagnetic compatibility health and safety aspects

6.1 Description of research works

6.1.1 Context

Since the last decade a lot of EU directives have come into force and for electric and electronic equipments, one of them is the directive 89/336/EEC on electromagnetic compatibility (EMC).
The directive as the other "New Approach" directives is quite light considering technical requirements. Based on harmonised standards compliance should be demonstrated.
The EMC research group of the University of Liège is specialized in research on complex and large systems, consequently power consuming, and the associated measurement methods.

6.1.2 Targets

Based on the technical specifications of the CHASM project, we had considered the following targets:

1) **to inform industry:**

The EMC Laboratory of the University of Liège has a lot of contacts with industry, doing a lot of pre-compliance and compliance EMC tests, doing also technical consultancy during the design of some equipments, giving many advices based on their knowledge of standards and also some trainings in different places (at Technifutur for instance).
In December 2003, we also organised with the "Interface Entreprises-Université" of ULG a visit of our laboratory for industries taking the opportunity that we were accredited by BELTEST according NBN EN ISO 17025 in May 2003. A large mailing had been done mainly in the Walloon region and more than 30 persons participated.

2) **research and transfer of the results to industry:**

Our research is deeply described in point B (Scientific methodology and experimental results) and is mainly on alternative EMC measurement methods for conducted and radiated emission applicable to large and powerful machines. We worked mainly on conducted emission.
Our aim was to develop and validate new standardised methods (we organise also a round robin test on conducted emission in 2005 in the framework of ABLE).

On the second topic, exposure to electromagnetic fields, we are continuing to participate, especially Véronique Beauvois, to BBEMG (Belgian BioElectroMagnetic Group) where we are the logistical support to medical, biological and psychological teams. We developed and improved magnetic field generating systems for in vivo and in vitro studies, helped these teams to define good measurement procedures, helped them also to review literature especially on electric and engineering aspects. A new contract had been signed in July 2005 with Elia to continue those researchs. This new contract will focused on the contact current hypothesis related to childhood leukemia and also hypersensitivity to electricity.
We are also member of *Grappe Mécatronique* (R.W.), *Cluster Auto-mobilité de Wallonie*, *GREPES* (Groupe de Recherche pour Electronique de Puissance en Environnement Sévère, leader Alcatel).

We participate also to three projects *First Haute Ecole* (R.W.), two with Rennequin Sualem (Liège) and CE+T (industrial partner), and one with CERISIC (Charleroi) and ABB Jumet (as our industrial partner). The topics are: emission prediction of embedded systems, immunity in industrial environment of wireless communication systems, prediction of conducted emission in powerful systems (as active filters).

The transfer of the results to industry is done through scientific publications and reports. We have many contacts and meetings with private companies as CE+T, ABB Jumet, Alstom Transport, Green Propulsion, etc. We hope to validate our new measurement methods and to use it for in situ measurements for industry (PhD thesis of Stéphane Coets for end 2006). Some preliminary measurements were done at the beginning of 2006 at Alstom Transport (Charleroi) on powerful drives.

3) To participate in standardisation activities

This participation is also developed in details in point A (standardisation activities following) and is mainly done by Véronique Beauvois.

6.1.3 Scientific method and results

6.1.3.1 Standardisation activities following

6.1.3.1.1CEB mailing list

Véronique Beauvois has subscribed to CEB (Comité Electrotechnique Belge) mailing list since many years. She is following especially standards on EMC from TC 77 of IEC and TC 210 of CENELEC for electromagnetic compatibility and TC106 of IEC for electromagnetic fields and health effects (TC 106 : Methods for the assessment of electric, magnetic and electromagnetic fields associated with human exposure).

6.1.3.1.2SLIM process & New directive

On the European Commission website, it was possible to follow the evolution of the revision of EMC directive 89/336/EEC which was called the SLIM process, SLIM means Simpler Legislation for the Single Market. There is a special part of this report on large machines and installations. prEN50217 is a project standard or guide which defines methods for in-situ emissions measurements (related to CENELEC TC210). This process had finally leaded to a new directive 2004/108/EC. This directive clarifies mainly many aspects of installations.

6.1.3.1.3Meetings and discussions

Véronique Beauvois participated to the following meetings in 2003:

- EMC Zürich 2003, February 2003, Zürich, Switzerland ;
- Workshop Cost 286 on EMC in Diffused Communication Systems, Current Capabilities and Future Needs, September 2003, Wroclaw, Poland
- Cost 286 meeting, December 2003, Brussels.

Marc Renard and Stéphane Coets participated to URSI Forum 2003, December 2003, Brussels.
In September 2003, a workshop on Research and Standardisation took place in CEN Brussels. Véronique Beauvois registered to this workshop but she was unable to participate, she had contacted Mr André Pirlet in order to receive information on this workshop. Mr. Pirlet sent us also information on the network CEN/STAR.

In May 2004, a new workshop was organised by DIN, the German national standards body in Berlin. The goal of this workshop was to explore early linkage of research and standardisation to optimise benefits for the economy. Marc Renard participated.
Véronique Beauvois participated to the following meetings in 2004:

- EMC Europe in Eindhoven 2004, September 2004 ;
- Workshop Cost 286 on EMC, November 2004, Hamburg, Germany.

Véronique Beauvois organised the following meeting in 2004:

- Workshop Cost 286 on EMC, March 2004, Liège, Belgium.

Stéphane Coets participated to EMC Europe (poster session, paper signed by Coets, Beauvois, Renard *et al*) and to URSI Forum 2004, December 2004, Brussels.

In the framework of the Cost meeting in Liège, we met John Newbury (from The Open University, UK), with whom we have scientific exchanges since 2004. We organised a measurement campaign in Belgium (Liège and Oostende) and France (Lille) for his team in June 2004. Then in September 2004, Véronique Beauvois went to Milton Keynes (UK) to participate to measurements. A trip was also organised in May 2005 in Scotland.

In May 2004, a workshop was organised by DIN, the German national standards body in Berlin, in the CEN/STAR network. The goal of this workshop is to explore early linkage of research and standardisation to optimise benefits for the economy. Marc Renard has participated.

In 2005, Véronique Beauvois participated to the followings:

- In April (14th & 15th), a Cost 286 workshop was organised on the Joint Technical Actions, and we presented a paper on our results in Liège ;

In September (19th & 20th), in Roma, Workshop on Electromagnetic Compatibility of Wireless Systems and a Cost 286 meeting.

6.1.3.2 **Scientific methodology and experimental results**

6.1.3.2.1Introduction

This work was realised with Stéphane Coets, a research assistant with the Belgian Industry and Agriculture Research Training Fund (F.R.I.A.) in the framework of his PhD thesis.
The aim of this work was to develop alternative methods for conducted and radiated emission for in situ measurements. The first step was to compare different methods to perform conducted emission measurements. Some methods are described in the standards. The performances and the utility of all the following methods are studied. The different methods considered are:

- the classical use of a Linear Impedance Stabilised Network (LISN) ;
- the use of a passive voltage probe when the LISN cannot be used (too high currents or not interruptible lines) ;
- a new method from the normalisation comities : using a LISN as a probe. (placed in parallel instead of in series) ;
- a capacitive clamp to perform voltage measurement (CVP) ;
- a capacitive clamp usually used for burst immunity tests ;
- a Rogowski coil to perform current measurements.

All the alternative methods developed up to now have got the same drawback: their results cannot be compared with the reference (LISN). Consequently a new method of measurement was developed.

For radiated emission, up to now, our study is limited to a state of the art of the existing methods and a preliminary analysis to identify potential solutions.

6.1.3.2.2Conducted emission measurement method

(a) Linear impedance stabilised network (LISN)
A LISN has two advantages. It prevents the EUT from the noise coming from the power mains, and it presents normalised constant impedance to the EUT (50Ω). This method is the reference for the standard and also for each measurement method developed in this research project.

(b) LISN in parallel on the power mains network
This is a new method propose by the standards. The LISN is used as a probe and inductances are placed between the EUT and the mains supply as a filter.
An analysis of the experimental results shows differences with the reference method:

- the standard deviation is more important.
- the average measurement differs from the reference for more than 5 dB in the low frequency band and above 10 MHz. Above than 20 MHz, the noise still persists in the results.
- some problems are solved with this method (higher currents), but limitations are still:
    - 1. large currents in the ground ;
    - 2. the power mains supply cannot have a residual current circuit breaker.

(c) Passive voltage probe
As mentioned in the introduction the reference signal is provided by the LISN's method. In case of too large currents, the passive voltage probe method is the only one described by the standards. But this method has got several drawbacks: the probe is placed randomly between the mains and the EUT; moreover the power mains network is different from the reference case because the LISN, which has been removed here, acts as a filter. Consequently, the results obtained with the probe may not be compared with the reference even if these results are good and accurate. Actually these results will always be an *overestimation* of the reference signal.

(d) Capacitive clamp (burst injection)

Metallic contact is not required for the clamp, but this device needs a larger place in the setup. A 107 dBμV signal voltage is injected and the measurement of the received signal is performed. The conversion factor of the clamp (generally used for injection of burst in immunity tests) can be deduced from this experimental calibration.

The conversion factor is very weak. So the attenuation is high. The results show that the clamp is useless.

(e) Capacitive voltage probe (CVP)

This method in now allowed by the normalization commitees (cf. CISPR 16-1-2). This device is essentially a capacitive voltage divider and its measurement setup is the same as for the "classic probe".

This device does not require any metallic contact to perform measurement and the mains supply does not need to be interrupted to insert the probe. Besides, only a small "free space" (5cm) around the point of measurement is needed. This probe presents a 20 dB attenuation factor in the measurement frequency range, which is better than the classic probe. Nevertheless the other drawxbacks still remain (position of the probe, lack of filtering, etc).

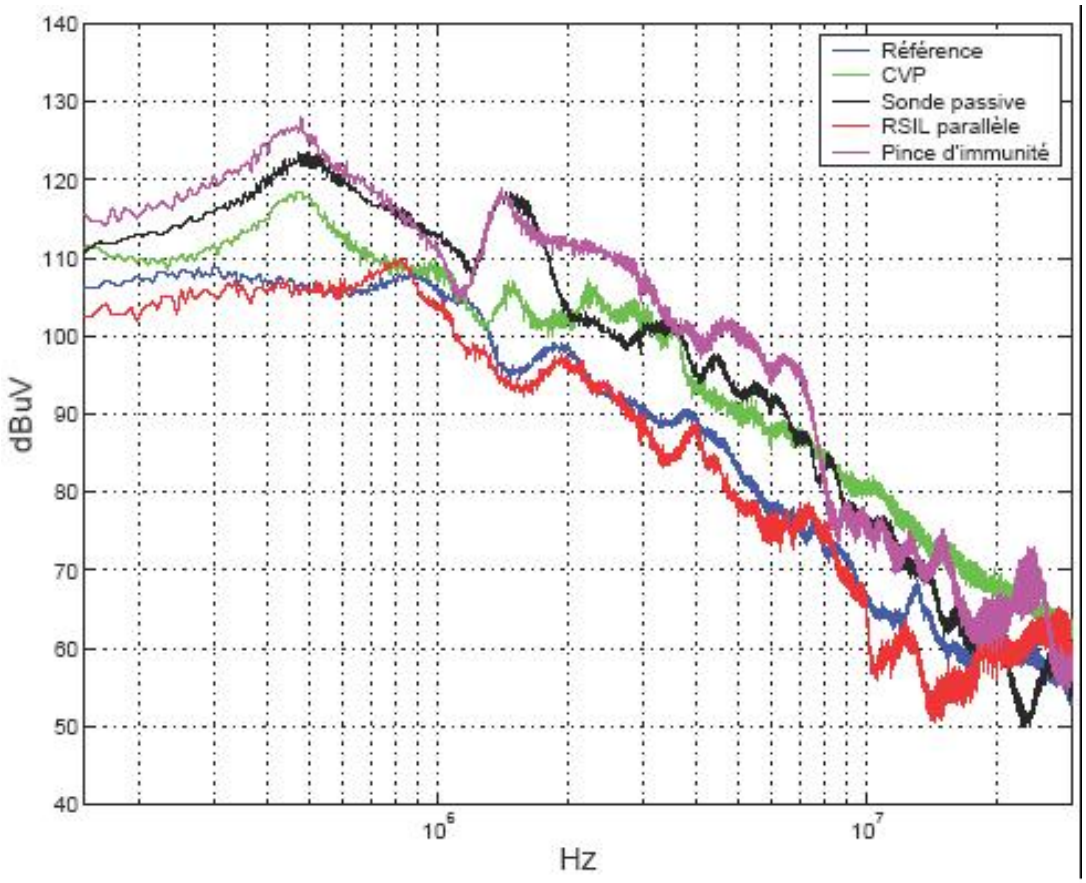


Figure: Comparative Results

6.1.3.2.3Original conducted emission measurement method

(a) Method

This method (called hereafter *indirect method*) is divided into two steps.
First, a model of the EUT (Equipment Under Test) is determined from measurements performed with *any* of the probes described above. It is obvious that these measurements are performed in non standardized conditions. Hence the results obtained depend from these conditions.
In a second step, this model is introduced in an equivalent circuit simulating the standardized measurement setup. Consequently, standardized and comparable results can be obtained.

(b) Active voltage probe

Some disturbances are low level signals. This is why they cannot be measured with the classical passive voltage probe described by the standards. Therefore an active voltage probe has been built to solve these problems. This probe has got a small attenuation factor, which is quite identical all over the frequency range (150kHz - 30MHz). Furthermore its input impedance is very large (100 kΩ, compared with 1500Ω). Besides the power mains signals must be removed from the receiver input. Consequently the active probe is composed of a high-pass filter and followed by an amplifier. The high-pass filter is built with three identical filtering cells placed in series. It provides an attenuation of 110dB at 50 Hz. When the global circuit has been designed, some of its components have been tuned up to meet both requirements, a small attenuation factor and a large input impedance.
This first probe we built provides a 2.9dB attenuation factor (instead of 30dB) and a 10 kΩ input impedance (instead of 1500Ω). A second active voltage probe based on a differential amplifier was built last year.

6.1.3.2.4State of the art on radiated emission

Requirements to perform radiated emission measurements

According to the standards, the measurements must be performed on an "Open area test site":

- the site must be clear of objects apart from the EUT and the measurement antenna (no reflection on other equipments) ;
- the measurement antenna must be placed 10 meters away (or at least 3m) from the EUT to be in the far field region ;
- the whole system should be placed on a metallic surface in order to standardise the reflective waves on the ground ;
- the antenna must be moved from one meter to four meters in height.

Problems encountered

The problems met with the measuring setup are numerous.
If the EUT cannot be moved and the measurements have to be performed *in situ*, the ambient can come from fields radiated by equipments placed nearby, from intentional and powerful emitters, etc.
The environment cannot be cleared from other equipments and reflective waves on these nearby objects are present. These waves may not be ignored. The ground reflective effects are difficult to analyse (unknown properties of the ground).

Place the antenna at 10 or 3 meters could be impossible and measurements had to be performed in near-field region.

6.1.3.2.5Proposed solutions

Ambient noise

The simplest solution to remove the ambient noise is to perform differential measurements with a hypothesis of stationary phenomena.

Near-field vs. far-field

The standards require the knowledge of the far-field maximum value. When only the near-field can be measured, a near-field vs. far-field transformation algorithm can be use to know the far-field.

Knowledge of the field by characterisation of the environment

Following a theory developed at NIST (Boulder, Colorado) the characteristics of the environment are determined by a quality factor. Two cases are considered:

- Reflective environment: this is similar to a reflective chamber whose theory is known. After determination of the quality factor, the measurement of the power gives the maximum field radiated.
- Transparent environment: the direct wave is the most important. The total power radiated by the EUT is measured and by knowing the directivity of the EUT, the maximum electric far-field is determined.

The characteristic behaviour of the environment is determined by a test: an electromagnetic pulse (known power) is propagated in the air. After a critical time, the power is measured. If the power is great enough, the environment is reflective. In other cases, the environment is transparent.
The total radiated power is measured by the three loop method in the low frequency range and by the reverberating chamber method at higher frequencies.
But the three loop method can be difficult to use. In case of great systems, the equipment cannot be moved and two of the three loop cannot be closed in practice. This method takes into account difficulties of the environment but only gives the maximum field and does not give the "shape" of the field which is useful for a deeper analysis of the problems.

Knowledge of the field by spatial sampling

To determine the field everywhere in the far field region, an idea proposed by Italian researchers is to measure the field at some points and to deduce by interpolation the field in the overall space. Of course, there is a minimum sampling ratio as in the Shannon theory.
Furthermore this method does not take into account the reflections on the ground surface and on the nearby objects.
Unfortunately this technique is time and money consuming.

Knowledge of the field by substitution

To get knowledge of the field in the overall region, a set of elementary electric and magnetic dipoles which radiate the same near-field are used. These dipoles have precise position, orientation, amplitude and phase. The steps of the algorithm are:

- measurements of the field at some point in the neighbourhood of the EUT ;

- to determine a set of dipoles radiating the same near field as the EUT at the same point;
- to calculate the far field from the set of dipoles everywhere in the space.

This technique has the same drawbacks as the Italian one.

6.2 Network working, users committee

We proposed for the users committee the following companies: Green Propulsion, Cebec and Gillam-Fei. We have continuous and preferential contacts with these companies.
As mentionned in target 1, our EMC laboratory has a lot of contacts with industry, doing a lot of pre-compliance and compliance EMC tests (for instance Technord, Medex, General Electric Medical, Siemens, Euresys, EVS, Deltatec, Gillam, CP Bourg, Bodart & Gonay, Schneider, Guiilaume, ABB Jumet, CE+T, Sony, IRM, ICM, etc.). Preliminary measurements were done at the beginning of 2006 by Stephane Coets at Alstom Transport (Charleroi) premises in order to compare different methods and validate his original one on powerful drives.
We propose also to send the following report to the users committee.

6.3 Diffusion and valorization

6.3.1 Publications

- *Accuracy of the measurements performed in conducted emissions in case of large systems* (S. Coets, V. Beauvois, J. Catrysse, W. Legros). EMC Zürich 2003, 9-13 Feb., 2003, Zürich, Switzerland, pp. 683-687.
- *Current Activities and Future Needs in Liège* (V. Beauvois). Cost Action 286 Workshop on EMC in Diffused Communication Systems, Current Capabilities and Future Needs, 17-18 Sept., 2003, Wroclaw, Poland.
- *Problèmes rencontrés lors de mesures en émission conduite dans le cas de grands systèmes* (S.Coets, V.Beauvois, J.Catrysse, W.Legros). TELECOM2003 et 3ème JFMMA, Oct. 2003, Marrakech, Morocco.
- *Measurements in radiated emission in case of large systems* (S. Coets, V. Beauvois, M. Renard). Proceedings of URSI Forum 2003, 18 Décembre 2003, Brussels, Belgium, pp. 66.
- *Measurements in conducted emission in case of large systems* (M. Renard, V. Beauvois, S. Coets). Proceedings of URSI Forum 2003, 18 Décembre 2003, Brussels, Belgium, pp. 67.
- *In situ radiated emission measurements in case of large systems* (S.Coets, V.Beauvois, J.Catrysse, M. Renard et W.Legros). Proceedings of International Symposium of Electromagnetic Compatibility. EMC Europe 2004, 6-10 Septembre 2004, Eindhoven, The Netherlands, pp. 169-173.
- *Improvements of conducted emission measurement methods in case of large systems* (S. Coets, M. Renard). Proceedings of URSI Forum 2004, December 2004, Brussels, Belgium, pp. 83.
- *Comparaison de méthodes de mesures alternatives en émission conduite pour les équipements de puissance*, , S.Coets, V.Beauvois, J. Catrysse and W. Legros, Proceedings of 13th Colloque International et Exposition sur la CEM, Apr. 4-6, Saint Malo, France, pp. 287-289.

- *Indirect method of measurement for conducted emission in high-power systems,* S.Coets, V.Beauvois, J. Catrysse and W. Legros, accepted to International Symposium on EMC, EMC Europa 2006, Sept. 4-8 2006, Barcelona, Spain.

6.3.2 Scientific missions

Véronique Beauvois participated to the following meetingsin 2003:

- EMC Zürich 2003, February 2003, Zürich, Switzerland :
  Véronique Beauvois and Stéphane Coets have participated to this conference which is the most important european conference in the EMC field. Stéphane Coets has participated to one of the oral sessions to present the following paper *"Accuracy of the measurements performed in conducted emissions in case of large systems"* (S. Coets, V. Beauvois, J. Catrysse, W. Legros)
  Our participation gave us the opportunity to meet many researchers.
- Workshop Cost 286 on EMC in Diffused Communication Systems, Current Capabilities and Future Needs, September 2003, Wroclaw, Poland :
  Véronique Beauvois is national delegate for Belgium in this Cost action. This workshop was organised in Poland with an MCM meeting in order to ask to each participating country to present his activity in the field. These presentations led us to propose one round robin modelling problem (influence of an emitting antenna on a cable near a metallic plane).
- Cost 286 meeting, December 2003, Brussels :
  Véronique Beauvois has participated to this MCM meeting. The main objective of this meeting was to finalise the definition of the round robin modelling problem. We have decided also to organise the next workshop and MCM meeting in Liège. The theme of the workshop was "PLC Communications" and was planned on March 25 and 26 in ULG.
- Marc Renard and Stéphane Coets participated to URSI Forum 2003, December 2003, Brussels. The main objective of this forum was to establish contacts between French and Belgian young research researchers. Two posters on the radiated and conducted emission were presented to explain and show our work and also to exchange ideas with colleagues from other laboratories on electromagnetic noise and interference.
- Véronique Beauvois participated to the following meetings in 2004:
- EMC Europe Eindhoven 2004, September 2004, The Netherlands:
  Véronique Beauvois and Stéphane Coets have participated to this conference which is one of the most important European conferences in the EMC field. Stéphane Coets has participated to one of the poster sessions to present the following paper *"In situ radiated emission measurements in case of large systems"* (S. Coets, V. Beauvois, J. Catrysse, M. Renard, W. Legros).
  Our participation gave us the opportunity to meet many researchers. There was also a Cost 286 meeting during this conference.
- Workshop Cost 286 on EMC Aspects of Wireless Communications in Transport, November 2004, Hamburg, Germany :
  Véronique Beauvois is a national delegate for Belgium in this Cost action. This workshop was organised at Airbus Research Centre with an MCM meeting in order to ask to each participating country to present his activity in the field.
- Workshop Cost 286 on Powerline Communications and Unstructured Networks, March 2004, Liège, Belgium :
  Véronique Beauvois has organised a workshop and a MCM meeting in Liège on March 25 and 26 in ULg. There were 20 participants from different European countries and really

interesting papers.

- Marc Renard and Stéphane Coets participated to URSI Forum 2004, December 2004, Brussels. The main objective of this forum was to establish contacts between French and Belgian young researchers. One poster on conducted emission improvements was presented to explain and show our work and also to exchange ideas with colleagues from other laboratories on electromagnetic noise and interference.
- In 2005, Véronique Beauvois participated to the followings:
- In April (14th & 15th), a Cost 286 workshop was organised on the Joint Technical Actions, and we presented a paper on our results in Liège ;
- In September (19th & 20th), in Roma, Workshop on Electromagnetic Compatibility of Wireless Systems and a Cost 286 meeting.