

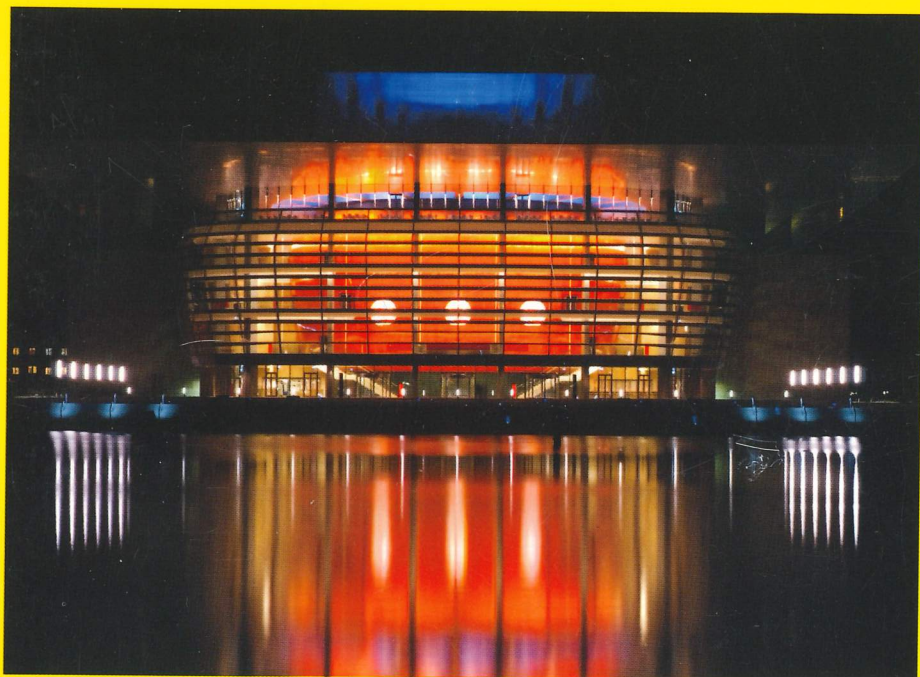
SVIB

V I B R A T I O N S

NYTT

Medlemsblad för Skandinaviska Vibrationsföreningen

Årg 25 Nr 2 Sept 2007



*Det nya operahuset i Köpenhamn
Vibrationsdagen 2007, med guidad visning av operahuset.*

Foto: Thomas Nördam Andersen



SKANDINAVISKA VIBRATIONSFÖRENINGEN

A collage of six images related to transport. The top left shows a road winding through mountains. The top center is a close-up of a tire. The top right shows a jet flying in a blue sky. The middle left shows a train. The middle center shows a man in a suit. The bottom shows a car driving on a road.

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Vem kan segla förutan vind? Vem kan ro utan åror?

Denne første leder fra ordførende skrives fra vores stuga i Småland hvor vi holder sommerferie de to første uger af juli.

Det er ca. 23 år siden at jeg første gang deltog i et SVIB arrangement; et seminar i Skogskloster, hvor jeg som Bruel & Kjaer specialist var inviteret til at tale om modal analyse. Det blev kærlighed ved første blik! Gode, kloge, venlige og humoristiske kollegaer i et specielt domæne hvor man i dagligdagen ofte er alene med udfordringer og problemer.

Men ikke mindst husker jeg en festlig aften hvor studenter-sangerne og Alf Olsson optrådte med sange og viser. Det var første gang jeg mødte den svenske visetradition en face, men som var mig velbekendt fra litteraturen og grammofonplader. Den musiske side har i alle de efterfølgende år fortsat været et kærkomment, tilbagevendende element i diverse arrangementer.

Siden blev det til mange, mange symposier, seminarer, vibrationsdage, studieture, og ikke mindst – private møder med SVIB kollegaer der gennem årene er blevet højt skattede venner.

Hvad er det der er så fantastisk ved SVIB? For mig at se findes SVIBs store styrke i den traditionelle idé at foreningens resurser er medlemmerne selv, at alle bidrager med deres særlige viden, erfaring og evner. Dette ses for eksempel i det princip, at alle foredragsholdere ved SVIB symposier også betaler fuld deltagerafgift; udfra den betragtning at alle i princippet er bidrager.

I dag tales der i business meget om betydningen af medarbejdernes netværk. Ja, det rækker så vidt at det ved ansættelsessamtaler indgår i vurderingen af kandidatens kvalifikationer. For mig at se er SVIB et ideelt sted hvor man kan udvikle sit faglige, kollegiale netværk. Personligt har jeg haft stor nytte af mit SVIB netværk; ved antagelse af medarbejdere, søgning af konsulenter, og ikke mindst har vores virksomhed en gang vundet en stor kontrakt på en direkte SVIB reference.

Efter mange år som menigt medlem, og de sidste mange år som viceordførende, er jeg nu blevet valgt som ordførende, efter at Martin Almgren efter 5 gode år, ifølge vedtægterne, måtte afgå. Det bliver svært at leve op til

den standard han satte og han er savnet i styrelsen! Jeg er ikke et ambitiøst foreningsmenneske, men efter at have nydt fordelene som medlem gennem mange år, er det vel ikke mindst som borgerligt ombud at jeg—med glæde og stolthed—modtager valget.

Som formand håber jeg at medvirke til at foreningens traditioner fastholdes. Måske er vi lidt for mange med gråt hår, så et af mine mål skal være at foreningen får en større tilgang af yngre ingeniører og videnskabsfolk,

med interesse for at deltage aktivt i foreningens aktiviteter.

Vores næste arrangement er Vibrationsdagen som i år afholdes i København den 22. november. Begivenheden finder sted på Gammel Dok, Dansk Arkitektur Center, som er et smukt og smagfuldt ombygget gammelt havnemagasin på historiske Christianshavn.

Programmet for Vibrationsdagen er under udarbejdelse, og færdigt for udsendelse i september. Men allerede nu kan vi sige at det bliver et skandinavisk bredt og spændende indhold.

Et vigtigt element i Vibrationsdagen er frokosten (lunchen). Opera Rotundens lunch nåede himmelske højder ved tidligere vibrationsdage, men mit bud er at disse vil blive overgået af Gammel Doks restaurant. A propos operaen: Der vil som

afslutning på dagen blive en rundvisning på Københavns nye Opera. Turen fra Gammel Dok til Operaen vil blive ad søvejen med den lokale vaporetta.

Når jeg indleder denne leder med Vem kan segla ... er det for at understrege den ordførendes begrænsede muligheder i foreningen. Vind og åre er for SVIB medlemmerne. Jeg vil her opfordre alle til at blive aktive medlemmer i en af AU grupperne. Det er her aktiviteterne sættes i gang og drives igennem.

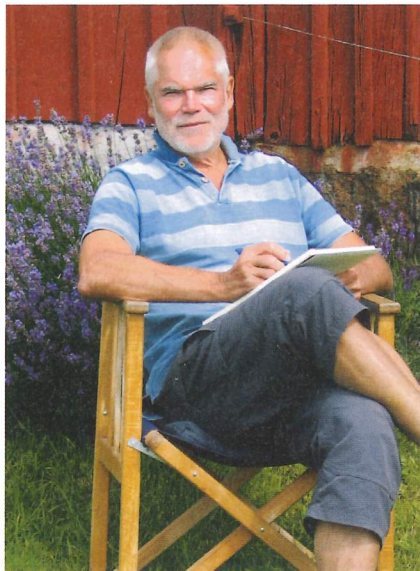
Til sidst vil jeg takke Kjell Ahlin, AU1 og Alf Olsson for et særdeles vellykket specialsymposium i maj, i Dunksers Kulturhus i Helsingborg. Må dette være inspiration for AUx.

God Sommer

Ole Døssing

Ordførende Skandinavisk Vibrationsforening SVIB

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Innehåll:

Vem kan segla förutan vind? Vem kan ro utan åror? - 1

Ole Døssing, Ordförande, SVIB

Sensor and Actuator Development versus New ADC Improvements - 5

Thomas Lagö, Anders Brandt, Kenneth Andersson, Daniel Maguire,

Active Noise and Vibration - 16

Dr Thomas Lagö

Study of active noise control in a passenger car - 34

Urban Emborg

Kurser, konferanser och läsvärt - 46

AU1 symposiet på Dunkers kulturhus i Helsingborg - 48

Alf Olsson

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Saven EduTech har bytt namn och heter nu Axiom EduTech

Sensor and Actuator Development versus New ADC Improvements

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Abstract

Historically, sensors, signal conditioners and the ADC were considered as separate entities and each unit needed to be designed to provide specific data. With today's low cost and high precision ADC systems, combined with very efficient DSP systems (Digital Signal Processor), new applications open that present system solutions that were not possible ten years ago. By having the ADC close to the sensor, many signal conditioning issues tend to be minimized. New materials, micro and nano technologies also open doors for miniaturized systems with unique properties. In this paper, some examples of such applications will be presented and some sensor and actuator technologies will be described, showing their main features.

Sensors

The sensing element is supposed to measure the physical unit without disturbing the actual unit we are measuring. This is a contradiction since we will always disturb the process, but the idea is to disturb it as little as possible. A key design parameter for a sensor is to build something that affects the process as little as possible, is small, linear, high resolution, low noise floor, easy

"interface" (e.g. a rugged voltage output) and often low cost. Typically, we are not able to handle all requirements simultaneously but new technologies enable more parameters to be address with fewer compromises. The first example is the "emerging" MEMS technology. By using clever filtering, a sensor element's performance can be enhanced or compensated, often referred to as "inverse filtering." Using modern DSP technology, a "sensor element" can then produce any of the typical units like displacement, velocity and acceleration, given that we are talking about an accelerometer. Inverse filtering and other "signal enhancement" technologies can be applied to the sensor system.

MEMS Sensors

One of the basic technologies for miniaturizing sensors is micromechanics, often called MEMS (Micro Electro Mechanical System). Production technology in this field comes from the electronics industry where thousands of identical structures are generated simultaneously with photographic methods. This method is called photolithography and it can be applied with a precision better than a thousandth of a millimeter. In the same way the electronics industry manufactures transistors, IMEGO in Sweden manufactures

mechanical structures comprising sensors. The low price per unit in mass production depends on producing thousands of sensors simultaneously with the same photolithography, thus sharing production costs, [1]. Historically, MEMS sensors had a rather limited dynamic range. Classical accelerometers typically have a dynamic range of about 120 dB. There are many applications where this is way more than needed. Therefore, MEMS sensors quickly found applications in the automotive industry where price was more important than superb dynamic range and accuracy. One application is as a crash sensor for the air bag. With time, these sensors have developed due to new production processes, silicon material and design. The MEMS sensors are still not in the 120 dB dynamic range, but have reached beyond 60-80 dB and are thus possible for applications where classical sensors could be the only alternative. The key advantages with MEMS sensors are that they are very low cost and typically very small.

By combining a low cost MEMS sensor element with signal conditioning and an ADC system, it is possible to linearize and enhance the dynamic range from the MEMS sensor. Such combined sensors are now beginning to emerge. A combined sensor system that contains signal conditioning, ADC and DSP (Digital Signal Processor) thus allows for:

- Linearization
- Filtering
- Calculation
- Prediction
- Monitoring
- Signal Classification
- More....

MEMS sensors can also be made rugged and since they are small to start with, a complete package of "everything" can become rather small and price competitive. An example of such a system is the "motion tracking accel-

ometer" from IMEGO in Göteborg, Sweden. Their motion tracking instrument IMT30 is built to track movements with extreme requirements on dynamics and resolution in order to meet the most demanding challenges. The IMT30 contains sensors based on micromechanics resulting in good robustness, reduced size and low production costs, together with DSP and electronics, [2].

Actuators

The actuator world is impacted by system solutions and new actuation technologies that can support large forces, frequency ranges and still rather low prices in volume applications. In mid 1970's, Philips presented the ultra-small loudspeaker with a vibration sensor placed in the loudspeaker membrane (cone) and in a closed loop, linearized the loudspeaker. For its size, this loudspeaker performed very well. Today, similar technologies are used for high performance stage systems where an enormous bass is supposed to be delivered. A regular loudspeaker would have to move too much and thus creating large nonlinearities that would not be appreciated by the listener. There is a golden balance between loudspeaker area and its displacement since the two create the volume velocity. For low frequency, it is often difficult to reach the required volume velocity using classical approaches.

Classical amplifiers used Class-AB stages and thus 80% of the power is used as a "heating element." 95% of the power left (20%) is typically burnt by the loudspeaker element due to its bad impedance matching to air, and low efficiency as an actuator. Therefore, only a few percentages of the power is really being used! A Class-D power amplifier stage uses a "switching approach" instead of a linear amplifier approach. By integrating the Class-D "delta-modulation" power amplifier together with the loudspeaker and a local feedback control, a very rugged and compact low frequency loudspeaker can be built.



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Such systems have been used for ANVC applications where power consumption, space and weight are essential factors. The best power amplifiers from the LAB.gruppen in Sweden use a clever combination of multiple technologies, [4]. It uses switch mode high efficient class D technology to supply a class AB amplifier with rail voltage that is tracking with the audio signal. The entire audio path remains analogue, with the signal never converted to digital pulses. There are no needs for the passive output filter that are common for all class D designs.

Smart Materials

The development in smart materials enables both new actuator and sensor technologies, and these new applications are being entered into with efficient solutions, not possible 20 years ago. Below, an outline of some selected areas is presented. They are not exhaustive and are only selected as examples with a focus on SVIB AU-1 activities.

Piezo Ceramic Patches and Piezo Film Material

Piezo materials have developed a great deal over the past 10 years. Today, materials of multiple shapes and sizes are available. By stacking piezo ceramic materials, it is possible to exchange force for displacement. The Acticut® system uses piezo ceramic stacks as the forcing elements. The development of stabilization systems for cameras also uses piezo ceramic material. Today, these actuator elements have entered many new markets. They are not so linear and thus it is important to either use their "linear range" or use a sensor and linearize them. These embedded designs are becoming more frequent. By shaping the film material, it is possible to actuate specific vibration patterns, like a specific mode. It is also possible to have an aircraft wing bend like a bird's wing,

allowing for less discretization as the flaps would do and thus losing important drag forces. Multiple demonstrations have been done and small aircraft vehicles (sizes like a humming bird) are then able to fly using less power, [3][4].

In skis, one piezoelectric stack is used to generate electricity while the other stack is used as the counter force. All of them are embedded and the damping effect that such a combined solution can accomplish is noticeable.

The ski application demonstrates the piezo electric effect as "reversible." Material stresses on the piezo ceramic material causes a voltage to be generated, while an induced voltage causes the same piezo ceramic material to deform. This effect allows integrated piezo elements to be used as a simultaneous sensor/actuator pair for applications like panel damping. The addition of embedded filtering, either digital or analog, is all that is required to close the loop.

Another blurring of the traditional distinctions of a sensor system can be seen in the use of piezo ceramic elements as both sensors and power generators for wireless in-tire pressure monitoring systems [17]. The peak voltage output of the piezo ceramic element is used to both estimate the radius of curvature of an under-inflated tire and to power the RF transmission circuitry communicating the condition to a central monitoring circuit.

Over the next ten years, the authors predict that multiple new embedded systems will show where integrated solutions using complete sensors, actuators, ADC and DSP systems are embedded and invisible.

Magneto and Electro Rheological Material

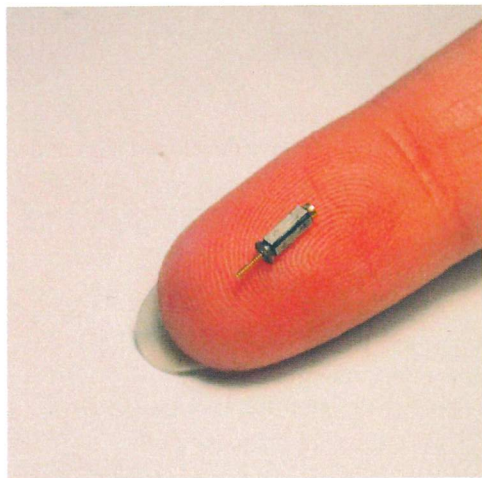
The magneto and electro rheological materials are beginning to find new and interesting applications. By using a magnetic field, it is possible to change the material's dynamic properties. Today, this is used to optimize, for example, an aircraft landing gear, for take-off, landing or taxiing, [8]. In the automotive and ship/boat industry these "actuators" are being considered as interesting alternatives to classical passive engine mounts – often referred to as semi active damping elements. Magneto rheological material has also been successfully designed onto heavy truck seat dampers that have been commercially available for many years now [16]. The ability to control the viscosity of the fluid dynamically using an embedded processor and control circuitry has proven particularly effective in the seat application, where a single characterizing spring rate and damping leads to an uncomfortable and possibly dangerous ride.

Magneto Strictive Material

Magnetostrictive materials have been used to create large forces and thus found applications in the turbine industry as bearing controllers. The first system design that then led to the Acticut® product was designed using magneto strictive actuators, [5][6]. However, it was not a great consequence of using strong magneto material in metal cutting. The actuators were quickly covered in metal parts. There are magneto strictive and electro strictive materials. The latter has its properties changed by an electric field as opposed to the other that uses a magnetic field. Both technologies are seeing new applications and the materials are improving.

Cameras – Mechanical systems going DSP – no sensor needed

Kenji Uchino, a Penn State professor with origin from Japan, began the "stabilization" industry for cameras. His methods included embedded sensors and actuators allowing for on-line mechanical stabilization of the "vibration induced by a non-stable operator." Later, it was realized that the same approach could be handled in the image and today multiple image stabilization methods are available in cameras of different prices and sizes, allowing for excellent low frequency stabilization of the image. It was not necessary to use actuators and sensors – it was possible to use the DSP to accomplish the same result using filtering. The sensor business is conservative and thus it will take time before such methods will be adopted despite the technology being available today.



A flat and wide structure (Windmill type), a PZT tube and a metal tube types are the primary targets for development. Motors as small as 1.5 mm have been developed with the maximum torque of 1 mNm, which will be utilized for medical micro surgery as depicted

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in the figure above.

Professor Uchino has also found an enormously large electromechanical coupling factor $k_{33} = 92 - 95\%$ in the solid solution single crystals $\text{Pb}(\text{Zn}_{1/3}\text{Nb}_{2/3})\text{O}_3\text{-PbTiO}_3$ and is now being applied for compact and high resolution medical catheters. The photostrictive effect is a phenomenon in which strain is induced in the sample when it is illuminated. We are developing photo-driven thick film actuators for space structure applications. Uchino has verified an optimum thickness ($30\text{ }\mu\text{m}$) of PLZT films for actuator applications. Below, a photo of a photo-driven micro walking robot with two photostrictive bimorph legs is depicted. Notice that neither electric power supply nor lead wire is required.



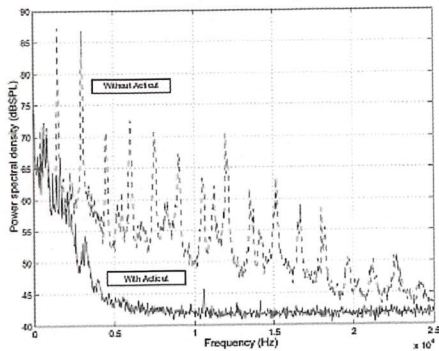
Acticut® is another system where embedded sensors and actuators have enabled a solution that has, for over 15 years, been frequently requested. Acticut® has received multiple industry awards during 2006 and is an example of new technology, embedded into classical industrial applications accomplishing unique results. In the Acticut® case, the sound and vibration that is a typical consequence of metal cutting is gone! As seen below, the sound has hit the noise floor. Multiple installations have been made and the interest is substantial. The technology represents a new era in cutting and the jury for the Smart and Embedded Award, (the minsTa award) stated: ".....it is an industrial revolution,"



The Acticut® system consists of embedded actuators and sensors that are placed inside the tool holder. By using an on-line control strategy, the chatter vibrations are inhibited. The result is a smoother surface, lower sound levels, faster cutting (in principle RPM independent), less wear on the tool tip and many other positive factors. Below, a photo of two typical Acticut® Smart Cutting tool holders is presented.



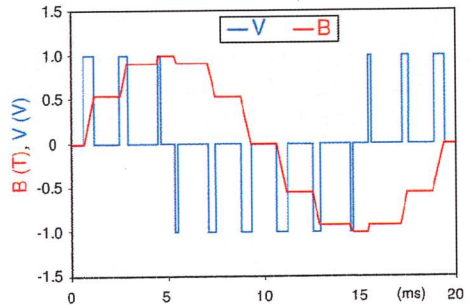
Below, a typical sound level result of the embedded Acticut® technology is presented. Sound levels in the cutting industry is a severe problem and very difficult to address using classical technology.



PWM Amplifier systems

The Pulse Width Modulation (PWM) amplifier uses pulses of varying length to accomplish the required signal voltage. By using a high frequency pulse train, combined with some form of low frequency filtering, a simple system implementation can be accomplished. An example of PWM is depicted in the figure below: the supply voltage (blue)

modulated as a series of pulses results in a sine-like flux density waveform (red) in a magnetic circuit of electromagnetic actuator. The smoothness of the resultant waveform can be controlled by the width and number of modulated impulses (per given cycle). Compare to the delta-sigma ADC approach, [10].



PWM can be used to reduce the total amount of power delivered to a load without losses normally incurred when a power source is limited by resistive means. This is because the average power delivered is proportional to the modulation duty cycle. With a sufficiently high modulation rate, passive electronic filters can be used to smooth the pulse train and recover an average analog waveform.



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High frequency PWM power control systems are easily realizable with semiconductor switches. The discrete on/off states of the modulation are used to control the state of the switch(es) which correspondingly control the voltage or current. The major advantage of this system is that the switches are either off and not conducting any current, or on and have (ideally) no voltage drop across them. The product of the current and the voltage at any given time defines the power dissipated by the switch, thus (ideally) no power is dissipated by the switch. Realistically, semiconductor switches such as MOSFETs or BJTs are non-ideal switches, but high efficiency controllers can still be built. PWM is also often used to control the supply of electrical power to another device such as in speed control of electric motors, volume

control of Class D audio amplifiers or brightness control of light sources and many other power electronics applications. For example, light dimmers for home use employ a specific type of PWM control.

The demand for a good audio power amplifier is quite high. Noise and distortion should often be more than 100 dB below full power. The load can be inductive, capacitive, resistive with impedances from very low (1Ω) to ∞ . Traditionally a linear class AB amplifier has been used to meet these demands. This is a good solution, except for the poor efficiency (about 20%) that make it more or less impossible to design amplifiers $> 1\text{kW}$. For ANVC applications the poor efficiency can be devastating.

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For at least 50 years, pulse width modulated switch mode technologies (class D) have been discussed as the solution for audio power amplifiers. Class D is not a digital amplifier! All pulse width modulated power amplifiers need negative feedback to get noise and distortion figures even close to a class AB amplifier. The benefit from class D is the high efficiency; about 85% -- a huge difference versus Class AB and its 20%. On the other hand there are a lot of problems that need to be solved when designing a rugged PWM amplifier. The passive output filter gives a frequency response that is depending on the load, which means that negative feedback must be sensed after the output filter. This can, on the other hand, make the design unstable, especially with a capacitive load. Ripple on the supply rails will inter-modulate into the audio. Half bridge designs will move energy in between the supply rails, which can destroy the amplifier. It is hard to get rid of switching transients on the output to meet the EMC regulations. If the two topologies are combined, an interesting design will occur. The basic technology is known since many years (ex. US patent Hamada 4.054.843 from 1975). It uses switch mode high efficient class D technology to supply a class AB amplifier with rail voltage that is tracking with the audio signal. The entire audio path remains analogue, with the signal never converted to switch mode pulses. There are no needs for a passive output filter that are common for all class D designs. Lab.gruppen was the first company that designed a professional high power audio amplifier (LAB 2000; 2x1000W in 1990) with this technology. The latest design from 2006, FP13000, delivers an output voltage of $\pm 200V$ with $\pm 90A$ of current.

Going from products to system solutions

In the old days, it was important to handle all of the components in a serial manner: Sensor,

cable, ADC, keyboard, DSP, Result and at last, the interpretation. All of this can today be embedded into the sensor and also reaching the desired control result using proper actuators. As can be seen from Acticut®, LAB.gruppen, ANVC systems, IMEGO, the Swedish MINST Consortium, Professor Uchino and many other applications, the world is changing from system components to system solutions. The previous barriers in terms of cables, ADC systems, keyboard etc. are starting to diminish. By using an out-of-the-box mentality it is possible to see new systems with new capabilities and the classifications Sensor, ADC, DSP, Actuator are likely to disappear. How do we know that we are talking about just a sensor? The "old" definition is "diminishing" with time and system solutions will become the sensing device: including power supply, sensor element, ADC, DSP, and the communicating device e.g. a wireless system. Distributed data collection units containing everything and also "talking to each other" are emerging technologies, each enabled by low cost, low power and efficient electronics solutions combined with the materials and an out-of-the-box mentality.

Summary

As discussed and presented in this paper, new solutions using built in sensors, actuators, ADCs, DSPs and communication devices are emerging technologies. New materials allow for both new sensor and actuator concept development and the low cost and high performance electronics that are being developed allows for nano-solutions to be achieved. Multiple examples from a variety of applications are being considered as practical and achievable in this new era of sensor and actuator technology.



Active Noise and Vibration

Control Methods and Applications in a Historical Perspective

Dr. Thomas L. Lagö, Acticut International AB (Falkenberg, Sweden)

Noise and vibration exposure for humans has been of interest for many years. Empirical data has verified that too high dose values can create multiple problems to a human body - often severe. Therefore, spot dose measurements have been used to verify that exposure levels are within acceptable limits. In 2006, the European Machinery Directive increased the responsibility for manufacturers and employers to make sure that limits are in compliance with legislation. The type of classical technology currently used, often employs passive solutions aimed at trying to reduce noise and vibration levels. For low frequency applications, these methods are often inadequate and lack the required level of performance. A smart combination of passive and active techniques can provide many improvements. Today, with possibilities for low cost and embedded electronics, and the rapid development of new actuators, a vast range of applications are possible for this combined approach. A financial advantage also exists when combining active and passive control methods. Today, multiple products utilize embedded "electronic muscles" that counteract harmful sound and vibrations in real-time - featuring advanced control systems. All this then becomes an invisible function in the vehicle, machine, or tool. The launch of such systems and successful acceptance requires international compliance with applicable standards. Via extensive international networks and scientific leadership in multiple organizations, we have managed to develop a range of new products meeting the requirements of international standards. One project, I-SPIDER, is aimed at addressing environmental parameters in schools: an area where our new smart and embedded technology plays a key role. Acticut®, the company that won the Large Embedded Award in Sweden (2006) is another example of how a smart and embedded system can accomplish a task that many people believe to be impossible. New sensor concepts and approaches in combination with consumer and automotive wireless and network solutions are key ingredients for success. It is impossible to imagine how the smart and embedded technology will revolutionize the sound and vibration business and open completely new business segments. This paper will outline these new markets and applications.

Background

The concept of destructing waves was already documented by Leonardo Da Vinci in 1400. He talked about decreasing water waves in a canal by having a separate canal interacting with the first canal. By properly adjusting the length of the "destructing" waves in the second canal, he could then make the water

surface calm, after the two canals had "effected each other."

Stokes performed observations in 1868 and J.W. Strutt followed some years later. In 1878 S.P. Thompson made the first known real attempt and not long after, Thorncraft and Yarrow investigated how a ship's "rolling"

motion could be compensated for by the inclusion of active means. In 1930, the first known patent was granted and invented by Coanda (see figure 1).

In 1936, the German engineer Paul Lueg applied for a US patent, covering an approach to active noise control in a duct. Since he didn't apply in Germany first, Hitler attempted to put him in jail. Thus, Lueg quickly moved to France, severely disappointed, and it is said that he never wanted to work within this field again. At the time, it was expected that researchers applied in Germany first, and certainly not in the USA.

Olson and May applied for a patent in 1953, covering the fundamental concept of a "silent chair," depicted in figure 1. Some time after, W.B. Conover from General Electric, presented results from transformer sound attenuation using loudspeakers.

In mid 1960's, Jessel and his team proposed the possibility of using Huygen's principle for active noise control. He combined this with Young's principle and they accomplished some great results in ventilation ducts. Key people continuing this work include a group of: Russian medical doctors, Onoda and Kido from Japan, Leventall and Swinbank from England.

The researchers and inventors at the time used analog control, and these systems could not be made adaptive. Thus, they suffered from instability and often produced more sound than they began with. The main principle was, however, correct, though the implementations could have been different. At the time, very few alternatives were available and thus almost naive implementations were made.

With the advent of digital signal processors (DSP), digital control systems began to be developed. Around 1978, approaches began to emerge, covering mainly air borne active noise control.

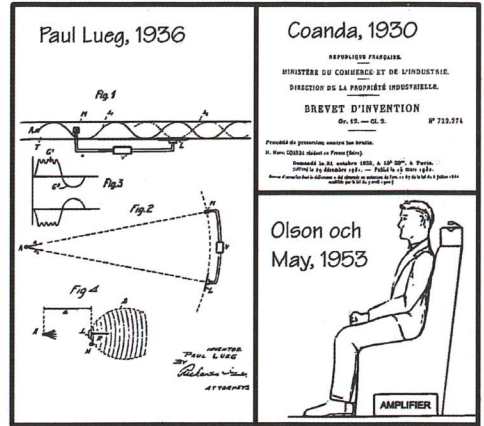


Figure 1. Illustration of early patents in the field of active noise and vibration control.

Most signal processing groups at the time focused on telecommunication, and an attenuation result in the range of 10-20 dB was more or less embarrassing. Thus, they often concluded that this is not a useful approach! What they didn't know was that there are many applications in acoustics where 10 dB represented a great result. This situation led to groups other than the classical signal processing teams developing systems and applications for active noise and vibration control.

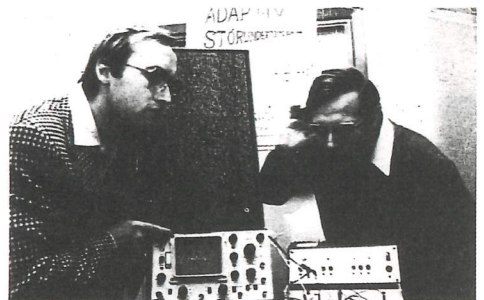


Figure 2. Dr. Eriksson and Dr. Lagö around 1980, demonstrating an early ANC system.

Professor Steve Elliott at ISVR (Institute of Sound and Vibration Research) in Southamp-

ton was one of the early researchers in this field. At the time, England was a leader in the field and boasted several key researchers who were working on the development of application solutions. Professor Chaplin applied for several patents and other people in England quickly followed.

Due to the commercial potential, financial and legal people from the USA developed a keen interest and attempted to steer the development work. A group was formed with the name NCT, Noise Cancellation Technologies in 1984. Due to a legal battle in regards to patents and ownership, Tom Hess decided to start another company ANVT, Active Noise and Vibration Technologies in 1987. A third group in the USA was formed,, Digisonix, mainly focusing on ventilation noise. The legal and marketing battle between NCT and ANVT was major and in 1994, the owner of ANVT decided to sell his company to NCT. All employees lost their jobs and part of that legal battle ended. Since then, both NCT and Digisonix has disappeared from the market. Other players have used the development and progress that Digisonix, NCT and ANVT initiated. Due to these legal battles, the ANVC technology had a back-lash, but today, focused applications have matured and new applications are emerging and thus the technology is finding its way into the market. Quite often, we might not even know that an ANVC technique has been applied.

Adaptronics – the Solution?

Smart Electronics and Mechanics

As mentioned before, the DSP and microprocessor has allowed for low cost implementations of ANVC technologies. Smart electronics have been combined with mechanical systems to form new generations of sensors and actuators. This allows for injection of vibration and/or sound waves into structures, not possible 20 years ago. It is foreseen that this development will expand even faster

and cost will decrease while performance increases. The cross-fertilization between multiple scientific areas is also positive even if not as frequent as one would hope. A focus on key industrial applications backed with relevant research is essential.

Adaptive systems

It is important for systems to be adaptive. Due to temperature, load or other parameters impacting the amplitude, phase and sometimes even the trouble frequency, the system must be adaptive in order to function properly.

It is possible to make an NVC system work for stationary conditions but will the system still operate when noise is injected and system parameters are changing? That is not always the case. In the figure below, the idea behind an early “adaptive system” is outlined.

Robustness

Robustness is a term often used to describe how insensitive the system solution is toward parameter changes and/or noise.

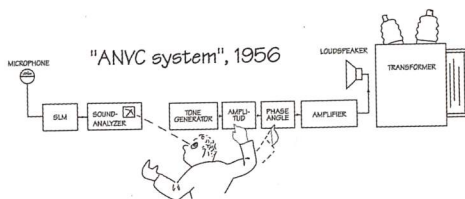


Figure 3. Illustration of an early “adaptive” system for an ANVC application.

It is not uncommon that research teams without a proper background demonstrate an ANVC solution after months of system parameter tweaking. Then, with some small changes in parameters, the system might become unstable or not perform correctly. The requirements and understanding of what is required to design robust solutions is often lacking. In principle, many research teams can demonstrate almost any ANVC system but very few can make them robust, enabling

them to function in a real life environment. As an example, Dr. Dan Maguire at Cooper Standard Automotive in the USA has developed a volumetric ANC system for vehicles that can be installed in hours without any having and prior information. This system functions very well and is also low cost.

Multi-Disciplinary

ANVC is a demanding area but also rewarding. It often involves: acoustics, mechanics, mathematics, physics, electronics, signal processing, actuators, sensors, optimization etc. If a research group is only covering one part, they typically redefine the industrial ANVC application into a lumped model with a clear focus on that group's competence. The project will then act more as an "educator project" than a "research project" since the results are not really useful but with time, the group might learn from it. Unfortunately, there are too few teams with a multi-disciplinary competence and it is often difficult for different groups to work together. After all, universities are supposed to be highly specialized in one topic only! For a robust and low cost system, with proper performance, a different arrangement is required – multi-disciplinary research teams with an open mind.

Out-of-the-box thinking

Knowledge is not always good. Many difficult problems have been solved by people not being told that the problem was "unsolvable." There are many examples of this. Again, if a EE person is presented a problem he will use his electronics background when viewing the problem. If the MEs were stuck, the EE "observation angle" might change the solution dimension drastically. Therefore, by having a team of experts with a variety of educational backgrounds, the likelihood of a successful solution is remarkable. The Acticut® system was developed based on this methodology. Mechanical engineers with a focus on the cutting process had tried to actively compensate the chatter. The basis is that the chatter is from self-induced vibrations and thus, RPM

dependent. Early investigations, made by Dr. Håkansson, verified that the correlation between RPM and the self-induced vibrations was zero and thus the basis was wrong. Even today, more than 10 years after he presented these results, experts on metal cutting have severe difficulties understanding why the Acticut® system works so efficiently. In the figure below, an illustration of a typical result switching the system on and off is depicted.

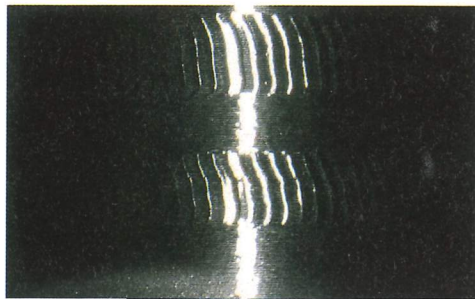
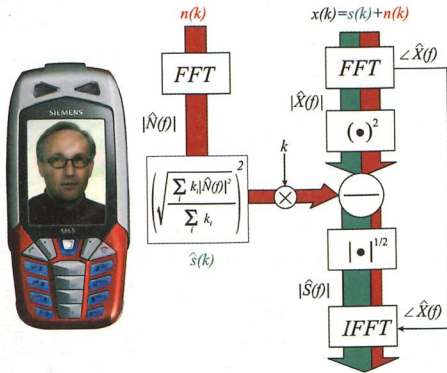


Figure 4. Illustration of the difference in surface roughness when the Acticut® system is switched on and off.

Solving the right Problem?

Background

Statement by the author: "It is better to solve the right problem right enough than to solve some problem 100% right." At a university, it is enough to solve a problem right to become a doctor. In industry, we must also solve the right problem to make money, even if it is not 100% solved. Therefore, a good feedback and formulation of the essential problem to solve must be handled in a clever way. When starting Blekinge Institute of Technology, it was a key ingredient to make sure that all Ph.D. programs had a focus on solving the right problem as the major quality factor. This has led to a great deal of success and many industrial implementations. One example is a noise suppression algorithm in Ericsson Mobile Platform based cell phones. There are multiple patents covering the implementation. The technology is being used worldwide in hundreds of millions cell phones.



Equation Benders?

Today's university situation where many universities are being charged for lab space, implies that they cannot afford a lab environment, allowing for real life simulations. The only way to handle the financial situation is to focus on computer simulations. This has many financial advantages. First, a computer is needed and this platform can also be used for the research work. Without a lab, reality can stay put by using models of reality where noise and other "difficulties" can be ignored. Then, a focus on nice looking equations and transformations of the solution space will generate multiple Ph.D. degrees. Will it work in real life? That is not the objective of the university and their comments is that the bending of equations is their part – then, the industry must take the next step and make it useful. Over the past few years, the author has received these type of comments many times from different research teams. It is important for a Ph.D. student to understand math and be able to bend and massage equations properly, but today there is a financial incentive to stay in the safe world of simulation, but that increases the gap between useful industry applications and university research.

Modeling?

Modeling of ANVC systems, including the environment where the system is required to

operate, is important. Often, an ad-hoc approach is used, based on engineering intuition and experience. After implementing the first system approach, many new conclusions and "data points" are received enabling an even more optimized design to be implemented. If a modeling should have been used as the basis for the first system, it is likely that the implementation would have failed and no data points would have been accomplished. This structured balance between modeling and reality is often lacking. It takes knowledge on both sides and a mutual understanding and respect – often lacking in research teams that are too specialized. The modeling work that the BTH team has performed, based on implementations, has led great understanding, enabling systems to be implemented with much less hardware, but with increased performance. There are other teams that have demonstrated this ability to combine ad-hoc, trial and error with modeling – in the right order. As a good example, the modeling of the metal cutting process and the dynamics behind it, has led to an industrial implementation with robust and efficient performance. The ability to predict what performance an active system will give, before even implementing the solution, is an important topic. Such system solutions exist and this type of modeling and prediction helps in setting realistic expectations for a system design. Also, a prediction and optimization of actuator and sensor locations helps in accomplishing good without having to test too much and using more control authority than necessary. Such development and methods have been created over the last ten years and provide excellent help with a complex problem, often with far too many solutions to even test, even in a life time.

ACTIVE Conferences

With regard to the international conference ACTIVE, arranged by I-INCE, universities are today, the major participants. The con-

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ference is rather math oriented and simulations and equation bending is unfortunately the consequence of many universities that are unable to afford a lab environment and thus lack proper applications and company support. Using computers for simulations is not only cheaper, it also assures that the problem definition is not contaminated by real life noise and other ugly parameters like nonlinearities. As described earlier, the gap is so large that the industry with many great applications does not even participate at the ACTIVE conferences. This is unfortunate and makes it even harder for universities to know if they are solving the right problem – no real feedback and/or brain stimulating applications. This should be changed and the ERAS initiative ECAS is one step in a positive direction aiming at overcoming such limitations. The Adaptronic congress is also an important platform for industrial applications where these “new” technologies are implemented.

Funding

Far too often, the evaluators of ANVC research proposals are people that are not really experienced in this business. They typically have experience from “acoustics” or “vibration.” However, they find the ANVC technology and solutions “sexy” and thus award money to projects that might have been previously completed in some other country. This is unfortunate but not that strange. If you do not know that things are already done and “ready,” awarding something that sounds “cool” is understandable. Therefore, there is a need for a strong European team that is able to focus funding on the right problems and making sure that teams with a capability of handling reality’s nasty implications in a clever way, are involved in a leading role. This takes a clear leadership role on multiple levels but it is possible. It is also essential to open the world of inputs and allow for both Asia and America to impact EU research directions.

Nu ska du lyssna väldigt noga!



Gör så här. Luta dig tillbaka och blunda. Ta några lugna andetag och koppla av. Vad hör du? Människor, fågelkvitter, datorsurr? En radio, ventilationssus, en industri? Du kanske känner vibrationer i huset från bilarna på gatan eller motorvägen?

Själv har vi lyssnat noga i 50 år och hört en hel del. Vårt jobb är nämligen att skapa tysta, vibrationsfria miljöer och produkter, och så bra förutsättningar som möjligt för tal, sång och musik.

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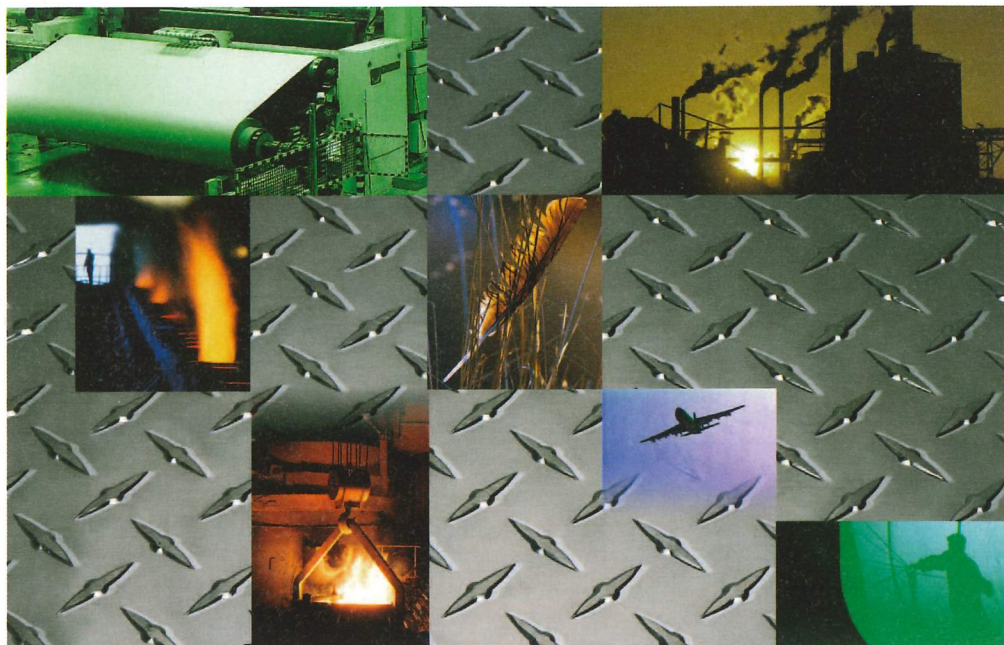
Tillsammans med industrin ser vi också till att ljudet från deras produkter låter rätt och förstärker deras image. Oftast är vi med i hela processen, från förstudie till färdig produkt.

Vi erbjuder också ett komplett utbildningsprogram för bland annat konstruktörer, arkitekter och byggherrar.

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Som riksmätplats upprätthåller SP referensnormalerna för samtliga centrala mätstorheter. Vi har följaktligen hela den spårbarhetskedja som moderna kvalitetssystem fordrar vid kalibrering av mätidon. Forskning och utveckling bedrivs kontinuerligt för att ytterligare förbättra noggrannheten.

Mature Areas

There are many areas today where ANVC technology is being used. By looking at university research and visiting an ACTIVE conference, it is easy to conclude that it will take another 5-10 years before system implementations begin to happen. That is not fully correct. Already today, there are many applications where ANVC technologies are being applied. Below, some examples will be covered. The list is not complete.

Headset

The headset and ear muff business is today filled with ANC solutions to enhance the handling of low frequency noise. Bose was early into the market and the two pioneers, Noise Cancellation Technologies (NCT) and Active Noise and Vibration Technologies (ANVT), are no longer in business. Companies like Sony, Pioneer, Sennheiser, Altec Lansing, Lightspeed, Solitude, Koss, Plane Quiet, and Creative have an ANC ear plug or ear muff with often excellent performance for the money. In the protection industry, companies like Sordin, Peltor, Hellberg and TechnoFirst have solutions that are performing well. I general, the most expensive product is not necessarily the best product.

Today, the technology is very low cost and it is possible to buy an active headset for \$35 with excellent performance. The maturity level for this segment can also be "measured" by the number of companies "copying" the technology.

Cameras

The vibration stabilization technique is today a commodity for cameras of all sizes and price ranges. The first system was developed by Dr. Kenji Uchino at Penn State in the USA. The system was developed for Minolta other manufacturers followed soon after.

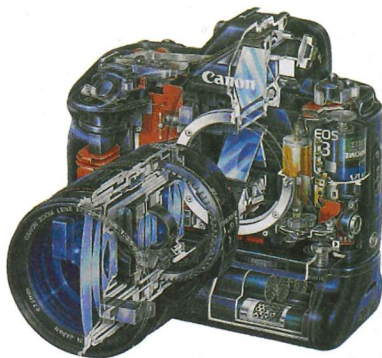


Figure 7. Illustration of a Canon EOS-3 and the vibration stabilization system.

A very early lens stabilization system was the Cern high energy acceleration system, developed in 1977. The dream of the CERN's founders, to achieve European eminence in "big" science, was realized in 1984, when Carlo Rubbia and Simon Van der Meer received the Nobel Prize in physics for "their decisive contributions to the large project which led to the discovery of the field particles W and Z, communicators of the weak interaction." The solution resulted in a Nobel Prize for the CERN group.

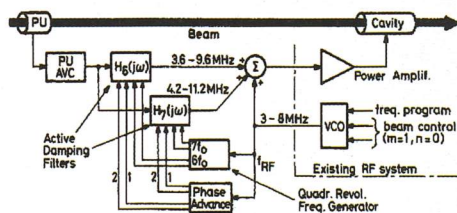


Fig. 7 Active damping system (per ring)

Figure 8. The fundamental principle of the CERN active vibration system from.

The technology stabilizing a lens or a beam is rather old. In 1977, a team at CERN in Geneva, Switzerland worked on the stabilization of the high-energy acceleration system, the PS Booster. Due to instabilities in the longitudinal

bunch, the system's accuracy was not good enough. A small team developed an analog active damping system, using a modal control approach, [35][36]. Four analog tracking filters analyzed the longitudinal modes and then these could be controlled, thus enhancing the accuracy of the PS Booster. The figures depict the main concept behind the control approach. Many inventions at CERN led to the W and Z particle, but without the active damping systems in the Beam Control System of the booster, and later the Lear Storage Ring, one would probably not have been able to make the beam gymnastics necessary to make the precise beam for the experiments.

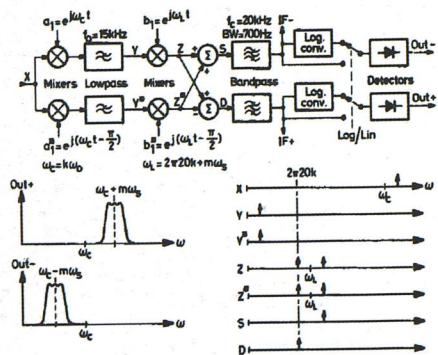


Figure 9. Drawing of the CERN stabilization system

Sports Equipment

Multiple systems for sports equipment have been presented. Not all of them have lived up to the claimed result and thus selected products have been withdrawn from the market. Below, a system implementation using embedded piezo-ceramic patches as dissipater is presented. This is actually a passive solution using active components and not really what we usually mean when we talk about active systems.

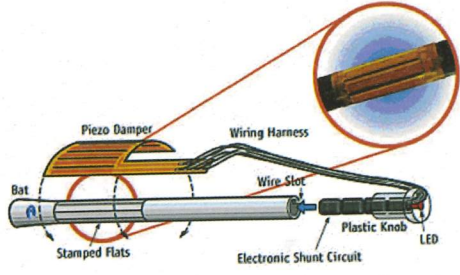


Figure 10. Illustration of an embedded piezo-ceramic patch that is used as a tuned passive damper.

The figure below depicts one design of such piezo-ceramic patches that can be embedded. Multiple attempts have been made to put them into ski's, both for snow and water. The results have been varied.

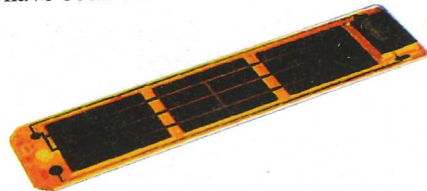


Figure 11. Illustration of piezo-ceramic patches made by Acx in the USA.

The piezo-ceramic patches for these applications were made by AcX.



Figure 12. Illustration of a snow skier. The vibrations in the ski can lead to less grip and thus loss of skiing performance.

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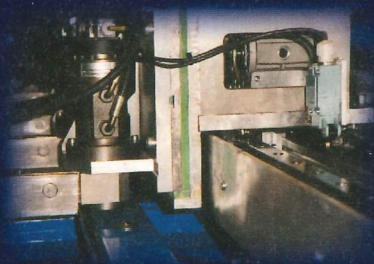
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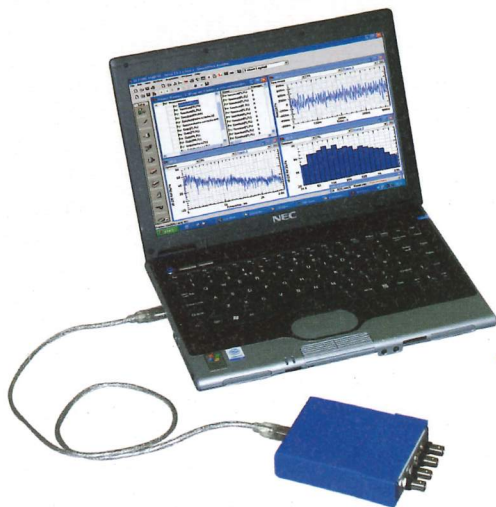
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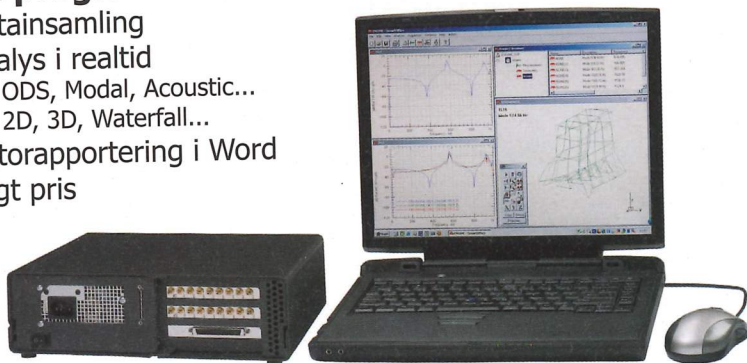
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K2 was amongst the first companies to introduce electronic vibration dampers. Part of the dissipation circuit is a LED that emits energy based on vibrations. They obsoleted these products since a LED, activated by the vibrations was not enough for the customers. Today, there are ski's that use two piezo-ceramic patches, one handling the damping and one supplying the electronics with energy. These ski's have documented performance.



Figure 13. Illustration of a mountain bike system that also uses a passive dissipative system using electronics.

These types of dampers are tuned to damp specific trouble frequencies in the bicycle frame. Since they are "passive," they do not need any power.

Aircraft

In the propeller aircraft industry, many commercial solutions are available in the market. Several of the propeller aircraft have ANC systems installed to lower the noise levels using less weight. The active systems are also adaptive, allowing for the performance to be rather good over a wide flight cycle range.

Today, there are few volumetric solutions for the broadband boundary layer and air conditioning noise, dominating interior noise levels in jet aircraft.

Multiple AVC systems have been applied to aircraft and helicopters, taking out annoying tonal components. This is often implemented using inertial mass shakers mounted on the

fuselage, lowering the transmission of vibrations that leads to sound radiation.

Vehicles

When the first volumetric systems were developed for the automotive industry around 1980, they were focused on engine noise. Today, that is not the main noise source. Road noise is a more dominant source but broadband plus random and thus much different in terms of control and ANVC implementation strategy. Multiple research programs have been focused on finding good approaches to handle road noise. By using semi-active suspension systems, a partial solution has been found, where the suspension parameters are adaptive and thus the car vehicle can change its optimal settings for different road conditions.

It was predicted that muffler systems utilizing an ANC approach would hit the market end of 1980's. Due to the environmental changes and the usage of a catalytic converter, the back pressure change was eliminated. The lowering of the back pressure that an ANC system created would have paid for itself by a lower fuel consumption. Today, these systems are being considered for other reasons – sound quality – a more and more important quality factor.

In the vehicle industry, the interest in using cylinder on demand is attracting ANC technologies back into the game. With such systems, it is possible to take out some frequencies but also add some other frequencies and thus create the proper sound, more so than a low sound level. A comparison versus passive technologies show that an adaptive and selective method can outperform any passive method. Multiple systems are being developed.

Volume Business

As seen for the previous discussion, there are multiple volume application areas where the ANVC technology can give clear advantages.

geous – adaptive and selective performance for a lower weight and lower price (?) – especially for low frequency. Today, multiple research efforts world wide are invested into clever semi-active actuators with a rugged design. This enables an effective usage of ANVC methods to be applied to engine mounts, still using a cost effective implementation. Some examples are (only examples – not exclusive):

Korea

In Korea, but also Asia in general, substantial money has been invested into building laboratories and environments allowing for industrial research using real life as the best teacher. Initiatives like Kwangju Institute of Science and Technology and Gwangju Institute of Science & Technology are producing many powerful solutions and the author recommends the interested reader to especially study the SAE conferences recently held where multiple papers from these groups are presented. The author has reviewed many

papers with a focus on sound and vibration improvements for the automotive industry. Their clear “reality focus” combined with proper math and modeling will pay back rapidly. New actuator concepts are also emerging from these well equipped teams, focusing on useful industrial solutions.

BMW, Mercedes and Audi

The top German automotive companies (sports cars not included in the list) have developed proprietary technology that can help in expanding the road handling capabilities without suffering from increased noise levels. The “classical” ANVC systems are not yet implemented but multiple semi-active and “point solutions” are emerging. The price/performance requirement for these applications are demanding and thus it is essential to find volume applications where ruggedness and reliability is satisfactory. It is not uncommon that top management’s hesitation against new technology has led to conservative decisions, despite ANVC systems being



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more efficient and lower cost compared with classical implementations (like balance axels, tuned dampers etc). Time, and other business segments using the ANVC technology, can create a “trust” that can change this, demonstrating the increased maturity of what ANVC solutions are representing. A technology demonstration is not enough since that is not the factor but possibly “fun” for top management to see new possibilities. There are very few “early adopters” in the automotive industry but the more other areas show maturity, the more likely the automotive industry are to follow. However, the technology is there today.

Below, a new actuator design has been presented by researchers at KAIST in South Korea, [16]. Their work included important modeling and sensitivity analysis, allowing them to further improve the design on multiple design criteria. This type of combined electrical and mechanical systems is an important development for ANVC volume applications.

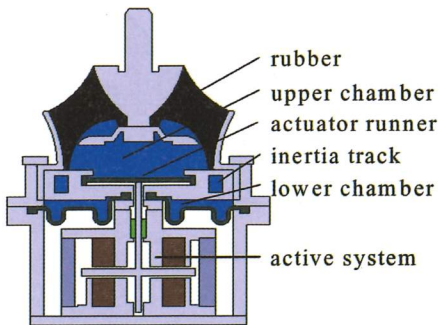


Figure 14. A novel actuator design made by a research team at KAIST in South Korea.

Acticut®

The Acticut® system has been presented at previous Adpatronic congresses. The system has matured and is now in an emerging volume application state. Several installations have been made and the company team has received multiple awards during the last few

years. 2006 was an especially satisfying year for Acticut through the presentation of the prestigious minSTa award. The award is presented by a group of Swedish electronics, nano and embedded systems technology companies, and research teams that select a company and product they feel represents something unique. Their award motivation described the Acticut® system as an “industrial revolution.” Below, an illustration is shown, outlining the substantial effect on the workpiece and the fact that the cutting noise has “disappeared.” Only the noise floor remains in place from the cutting process. The system consists of a Smart Tool Holder and a Smart System Controller.

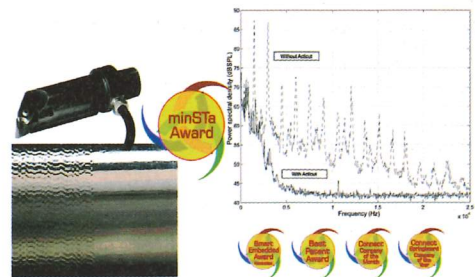


Figure 15. Illustration of an early “adaptive” system for an ANVC application.

Future Business

Smart Electronics and Mechanics embedded into robust and invisible solutions are entering more and more applications. The line between classical ANVC and adaptive systems will gradually diminish. The semi-active systems are good examples of this. Magneto- and electro-rheological actuators and their applications are other examples. New mechanical “loudspeakers” like the “Flap” is another example. “Flap” actuators have been presented by TechnoFirst in France and ERAS in Germany and successfully implemented in muffler systems. The need for an “industrial perspective” on

adaptronics and ANVC is essential. It is not realistic to believe that an ANVC technology will be used just because it is an ANVC technology. The factors and advantages that the technology bring must be clear. Too many research teams try to solve "any sound and vibration problem" using an ANVC approach since the technology is "appealing" to some selected funding teams (this is not a general statement). Such implementations and research can give the technology a bad reputation, since the project "verifies" that the technology is not capable of solving real life problems in a cost effective manner. The reason for that was not the technology as such, but a bad usage of it. Again, this folds back to the need for teams with a clear industrial experience and multi-disciplinary talents in their scientific approach. Solving the right problem is more essential than simple solving a problem right.

Just like many (most?) headsets and ear muff products of today, they are using ANVC techniques without customers really knowing about it. Other system solutions are being implemented into other areas using smart and embedded technology.



Figure 16. Illustration of a wide range of industrial applications where embedded and smart solutions can make a world of difference – often utilizing ANVC technology

With the use of wireless technology in combination with distributed sensors and actuators, applications that today might not be possible, will be possible tomorrow. The development rate is high and driven by many other needs and technology advancements.

The international consortium behind the I-SPIDER research program (International Study Program for In-Door Environmental Research) uses embedded and smart technology to help optimize classroom environmental parameters, for example, aiming at improving study performance. The coupling between low frequency, noise or air quality has been studied in multiple projects but no optimization has been performed. With these new embedded solutions, better documentation of environmental parameters can be accomplished and invisible solutions created. Research groups interested in this topic should contact the author.



Figure 17. Illustration of new business segments and their need for new solutions.

Conclusions

ANVC methods as a concept are old but are today finding more and more industrial applications due to the rapid development in adaptronics. The combination of smart and adaptive electronic and mechanical systems allows for handling of low frequency noise and vibration in a more efficient manner

as compared to passive methods. Many of today's implementations are invisible to the naked eye since they are embedded into the vehicle or structure. Existing volume applications include headsets, ear muffs, aircraft and multiple vehicle applications. Using smart and embedded mechatronic systems, solutions with extended performance are helping to fulfill demanding environmental requirements. The low frequency vibrations would require too much mass and volume and it is very challenging to make the systems adaptive, following system changes. Systems using adaptive and smart abatement are expanding. There are a vast number of tall buildings using adaptive compensating masses, controlling the first bending mode, helping in stabilizing the movement of the

building against wind and/or earthquake excitation. In vehicles, suspension system dynamics and interior noise levels (exterior?) can be extended using adaptronics. The cutting industry's sound and vibration challenges are finding new hope based on embedded electronic muscles into existing tool holders, like the Acticut® system. Then, solutions to increasing vibration challenges induced by new materials like hardened steel, titanium and cast iron. Increased environmental concerns are forcing manufacturers to create less waste material and lead has been banned in the steel. It is likely that this type of smart, embedded and adaptive technology will find new applications, maybe far from what we are able to grasp at the moment.



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STUDY OF ACTIVE NOISE CONTROL IN A PASSENGER CAR

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INTRODUCTION

Low-rpm boom noise has been found to be pronounced in the rear passenger seat of the four-cylinder-powered Saab 9-5. This boom noise is dominated by the engine firing frequency (2nd order harmonic of the engine rotational speed), and target levels

are exceeded by approximately 10 dB in the 1600-1800 rpm speed range during acceleration in 5th gear.

The objective of this study was to investigate the boom noise problem and demonstrate the potential for active noise control of the low-

rpm boom noise problem in the Saab 9-5. The project was carried out in 3 phases. The first phase focused on the development of a suitable control algorithm for boom noise cancellation. The ANC system requires a control algorithm that adapts the cancellation to the fast variations of the sound field over time. The second phase dealt with source and sensor placement and included a detailed mapping of the sound field in the car as well as the measurement of transfer functions between speakers and microphones. The third phase covered validation and demonstration of an ANC system, including subjective evaluations.

Basic Concepts

The concept of active noise control has been known since the 1930's, but until recently it was not practical to implement the theory effectively, because the necessary computing power was not available. Now, however, with the availability of modern high-speed digital signal processors and control techniques, the concept of active noise control can readily be applied to suppress noise. Examples of the successful application of active noise control are the Saab 340 and the Saab 2000 turboprop aircraft.

The basic principle of active noise control is to introduce an additional source of sound, namely a secondary source, so as to provide an out-of-phase image of the primary sound field (that is, the sound for which control is desired). The degree to which the secondary field matches the primary field determines the effectiveness of an active control system. Ideally, if the two sound fields were matched exactly, both in space and time, the noise would be completely eliminated. In practice, the match cannot be perfect, and the mismatch limits the degree of noise control that can be achieved. In examining the potential for active noise control it is therefore important to consider both temporal and

spatial matching of the secondary field with the primary field.

Temporal matching is concerned with the degree to which two sound fields are correlated in time. For temporal matching to be perfect the anti-noise sources need to be provided with instantaneous information about the primary noise. This is normally described as a causality constraint. In practice there will be some delay in the gathering, transmission, and processing of this information: as the source varies, the antisource will follow it a short time later. The effect of the delay on matching the two sound fields will be small only if the delay is small compared to the frequency of the primary noise. That is why active noise control is more effective for low frequencies. There are ways of overcoming the delay in some applications. Advance information, describing what the source of noise will do later, may be used by the control system. If the noise is repetitive in nature, knowledge of the repetition rate and the past behavior of the source allows the system to predict the behavior of the primary source and overcome the delay.

Spatial matching means that the positions and the shapes of the primary and the secondary sound fields coincide throughout the region where the control of sound is desired. Clearly, the more complex the original sound field, the more difficult it is to generate a matching shape. The more secondary sources that are used, the better the match and therefore the better the reduction of the original noise.

The frequency spectrum associated with the primary sound field is also important for spatial matching. At low frequencies, where wavelengths are long, a small mismatch in the positioning of the secondary sound field will not have much effect. At high frequencies, however, even a small mismatch may

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be a significant portion of the wavelength, and therefore the two sound fields will not coincide to produce uniform noise reduction throughout the space.

Algorithm

Application of active noise control in a car requires an algorithm able to track the rapid rpm changes during acceleration. Since the noise phenomenon is repetitive in nature, a so called feed-forward algorithm has been selected. This algorithm uses advance information provided by a reference signal, in this case the engine ignition pulse. This reference provides information about the engine speed but nothing about the sound amplitude. A block diagram of an ANC system is shown in Figure 1.

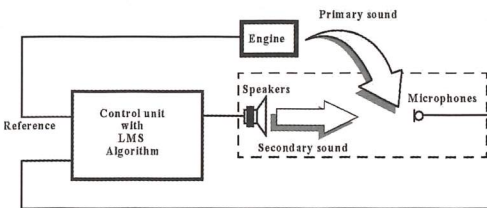


Figure 1 Block diagram of ANC system

The control unit generates output based on the reference signal and sends it to the secondary sources, i.e. speakers in this case. The sound from the speakers and the original primary sound field generated by the engine add together to form the combined sound field, which is detected by the control microphones. These microphone signals are fed to the control unit and the algorithm adjusts the output so that the signals from the microphones are minimized in a least-mean-square sense, hence the name LMS algorithm. The control microphones and the speakers must be properly positioned to successfully perform the spatial matching calculated by the algorithm.

For application in the Saab 9-5, a control

algorithm has been designed that combines high reduction throughout the compartment with robustness for rapid rpm changes and different driving conditions.

IDENTIFICATION OF SOUND FIELDS

General

A combustion engine produces vibrations that are repetitive in nature. These vibrations propagate through the structure of the car and result in boom noise inside the car. In a four cylinder car, like the Saab 9-5, the 2nd order component of the noise is of great importance.

For the characterization of the primary noise field inside Saab 9-5, noise measurements were performed in 48 microphone positions. Twelve of them were monitor microphones, i.e. typical ear positions and positions to increase the understanding of the sound field. The remaining 36 were potential control microphones attached to the inner surface of the passenger compartment.

For characterization of the secondary sound field inside Saab 9-5, transfer functions from potential ANC loudspeakers to the 48 microphones were measured. The data on primary sound fields and transfer functions were acquired in order to provide input for the definition of an optimal ANC configuration.

Primary Sound Field

Figure 2 shows the sound pressure in the rear seat as a function of both engine rpm and frequency (spectrogram) for a typical acceleration. The high level of the 2nd order shows up very clearly as a red crest in this plot. The highest levels are found in the 1600-1900 rpm speed range.

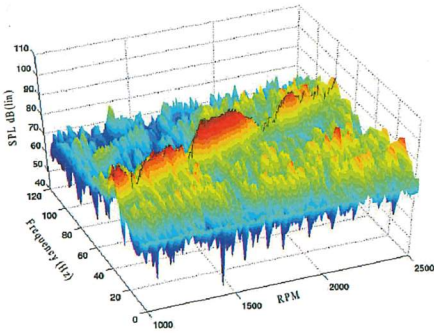


Figure 2 Spectrogram for left rear seat monitor microphone. ANC OFF

The 2nd order component (the crest) transformed to X-Y plots, is found in Figure 3. The 4 monitor positions are the positions at the passenger ears (see Figure 7). The 2nd order noise levels are plotted as a function of engine rpm. The straight line is the Saab Automobile target line for the Saab 9-5. The characteristic low-rpm boom is found in the rear seat in the 1600-1900 rpm speed range. In this region the target levels are exceeded by as much as 10 dB.

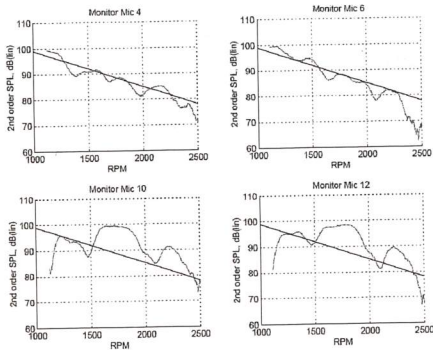


Figure 3 2nd Order noise levels in 4 of the monitor positions.

In order to gain a better understanding of how the primary sound field develops during an acceleration the 2nd order component is plotted as a contour plot. The composition of the microphone grids in such a plot is illustrated in Figure 4. The monitor microphones are separated from the control microphones.

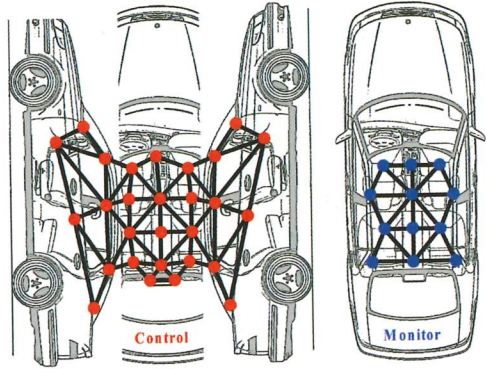


Figure 4 Composition of microphone grids for sound field plots.

Figure 5 shows an examples of the 2nd order sound field in the Saab 9-5 at 1275 rpm and 1700 rpm. The 2nd order noise level at 1275 rpm is high and uniform throughout the passenger compartment. At 1700 rpm the Figure shows the modal character of the field with a pronounced node in the front seats while an anti-node creates high levels in the rear passenger seats.

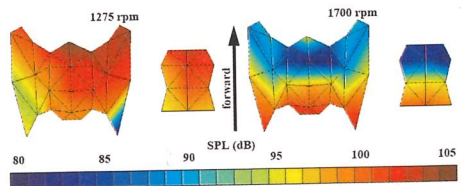


Figure 5 2nd order sound field at 1275 and 1700 rpm, test a0-3 (1999-04-20).

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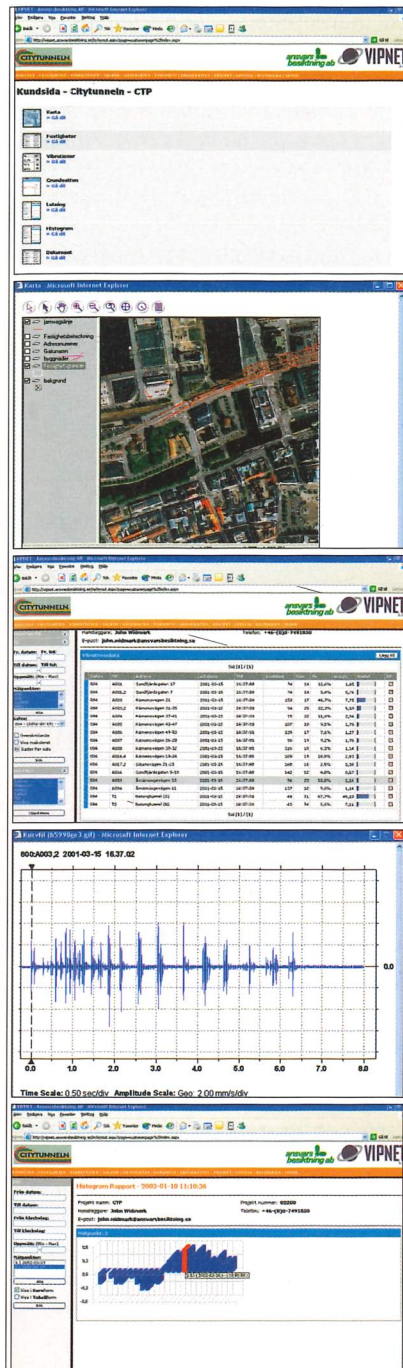
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Secondary Sound Field

In the work of defining an optimal ANC configuration, a model of the sound field generated by the secondary sources, i.e. the loudspeakers, is needed. Therefore the transfer functions between potential loudspeaker positions and the 48 microphones were determined. Figure 6 shows 6 of the existing speakers plus 17 additional potential loudspeaker positions

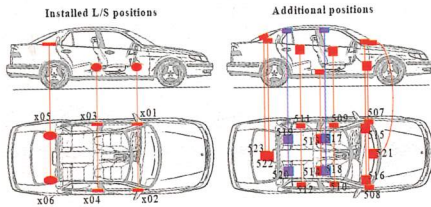


Figure 6 Loudspeaker positions.

OPTIMIZATIONS AND SIMULATIONS

Introduction

The purpose of the ANC system is to minimize the 2nd order engine noise at the passenger ear positions. Those positions constitute the monitor positions for this application as shown in the Figure 7.

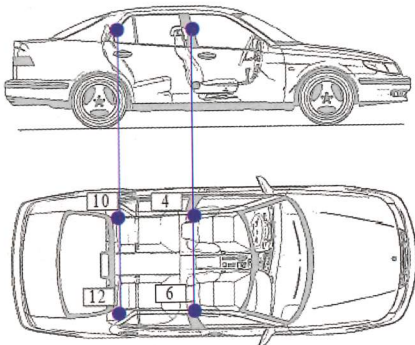


Figure 7 Monitor microphones at passenger ear positions.

The control microphones connected to the ANC-system are preferably placed in the headliner or on the A-, B- or C- pillars. The fact that the control microphone positions are not coincident with the monitor positions makes this application special. The maximum potential performance of the system, as well as the robustness of the system, depends to a great extent on the selection of the locations for the loudspeakers and the control microphones. The goal of the optimization procedure, then, is to determine sets of locations for the speakers and the control microphones, out of all possible sets of speakers and microphone locations, that provide optimum control at the monitor positions.

Extensive optimizations were carried out. The most promising configuration is shown in Figure 8.

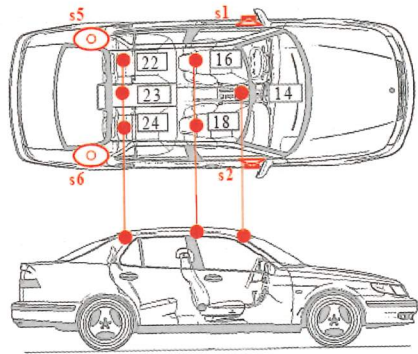


Figure 8 Selected ANC configuration with 4 speakers and 6 microphones.

The selected configuration has 4 speakers and 6 microphones. This configuration has very good performance in both rear seat and front seat positions with residual levels well below the target line. It uses only existing internal audio speakers and all of the microphones can be installed in the headliner.



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Performance Simulations

The performance of the selected configuration was simulated for many different driving conditions. The purpose was to investigate the robustness of the control system with this configuration.

The selected configuration was found to be robust for the different driving conditions that were simulated. This includes driving with rear left window open, very quick acceleration though the gears and different cars with slightly different primary fields.

Validation of Simulations

To validate the simulations all signals to and from the control unit were logged both with ANC on and off.

Figure 9 shows a comparison between the simulated 2nd order noise levels for ANC on and the actual measured 2nd order noise for ANC on in the 6 control microphones of the selected configuration.

The comparison shows excellent agreement between simulations and measurements. Hence the procedure regarding the optimizations and simulations is valid.

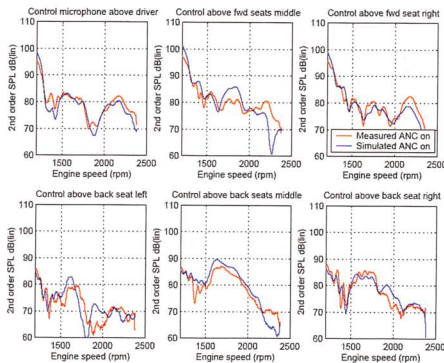


Figure 9 Measured and simulated results in control microphones.

SYSTEM DESCRIPTION

A laboratory ANC system was installed in the Saab 9-5 test car. This system consisted of 6 microphones and a control unit. The system also used the ignition pulse from the engine control unit and the 4 bass loudspeakers in the Harman Kardon audio system of the car. The system layout is shown in Figure 10.

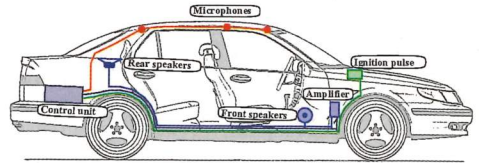


Figure 10 System Layout

The microphones were mounted in the headliner, embedded in the panel so that they were invisible. The microphones are similar to those in mobile phones.

The control unit acquires the ignition pulse and microphone signals. The algorithm of the control unit calculates the speaker outputs in order to minimize the signal in the control microphones. The control unit then sends the output to the loudspeakers via the mixer. In this demonstration case the control unit was a PC fitted with digital signal processing boards. In addition a mixer was mounted in the power amplifier of the audio system in order to combine the signals from the control unit with the signals from the radio/CD unit.

ANC SYSTEM PERFORMANCE

The performance of the ANC system, in terms of noise reduction, was measured. Figure 11 below shows the measured 2nd order Sound Pressure Level in dB(lin), for the selected configuration, in the 4 monitor positions.

The result shows very high reductions in the rear microphones throughout the acceleration range. Also reasonable reduction is shown in the forward microphones.

Residual levels well below the target line over the rpm range of interest were obtained.

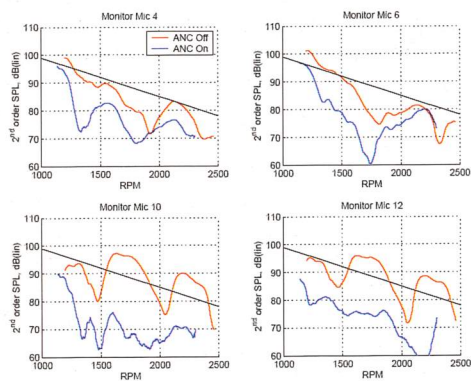


Figure 11 2nd order SPL in dB(lin) for monitor microphones with ANC On/Off.

To visualize the sound field distribution, colour contour plots can be generated for all of the microphones shown in the grid in Figure 4. Figure 12 shows the sound field at 1275 rpm with the ANC system switched OFF and ON. The original high levels are reduced both in the front and the rear seats.

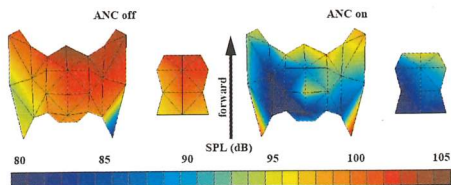


Figure 12 2nd order sound field at 1275 rpm.

At 1700 rpm in Figure 13 the original levels are high in the rear part but low in the forward part. This is the typical boom problem where the driver is not aware of the problem in the rear seats and hence cannot adjust the driving condition. When the ANC system is ON the noise levels are substantially reduced throughout the passenger compartment. The high levels in the very rear of the car, with ANC on, are due to 2 microphones located very close to the rear loudspeakers. These 2 microphones are in the near field of the speakers and thus give an indication that these speakers are active in controlling the noise.

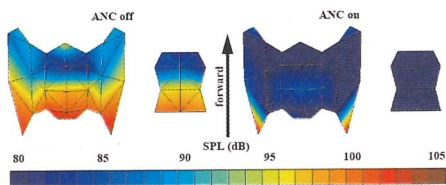


Figure 13 2nd order sound field at 1700 rpm.

Figure 14 shows the spectrogram for ANC off and on in the left rear passenger position. It is evident that the ANC-system efficiently cancels the 2nd order component. The limited reduction at low rpm is due to the poor low-frequency performance of the speaker elements.

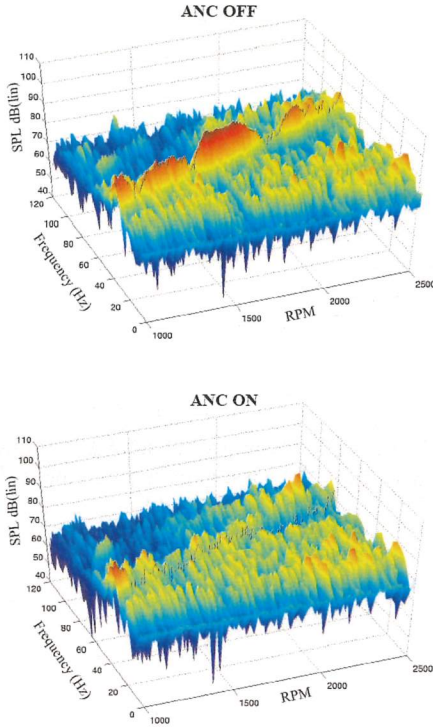


Figure 14 Spectrogram with ANC Off and On.

CONCLUSIONS

The results of this project show that active noise control can be an effective solution to the boom noise problem in the Saab 9-5. During acceleration in 5th gear, noise reductions of 10-30 dB were measured in the 2nd order engine noise at the passenger ear positions. The resulting noise levels are well below the Saab target line over the whole rpm range of interest. Furthermore, the sound field at the 2nd order with active noise control is globally reduced throughout the passenger compartment. In addition, the ANC system appears to be very robust for rapid rpm changes and for different driving conditions. It is also

interesting to note that the required power for driving the loudspeakers was found to be low.

The subjective evaluation, performed during demonstrations in Trollhättan, showed an improvement by 3 units in the so called GMUTS (1-10) scale. This is a very substantial improvement.

It is envisaged that the present study can form the basis for further work on active noise control in the Saab 9-5 or other Saab models. The study shows that greater noise reduction is possible at a lower frequency range if suitable secondary noise sources are employed. Currently the performance at idle and takeoff speeds is poor, since the audio-speakers cannot produce sound of suitable power at these low frequencies. The algorithm developed in this study also has the potential for noise reduction at frequencies higher than the boom noise problem. Results indicate that control up to 6000 rpm should be possible.

Another interesting application that deserves consideration is active noise control of road noise. The main difficulty lies in identifying references with a high coherence to road noise. If that can be achieved it is most likely that active noise control for road noise can also be successful.

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Kurser, Konferenser och Läsvärt

Kjell,

As you may know, I am the editor of Harris' Shock and Vibration Handbook published by McGraw-Hill, NY. We are now starting work on the sixth edition of this Handbook, which will constitute a major revision of the fifth edition published in 2002. Specifically, we are rewriting many of the chapters with new authors to fully update the Handbook. One of the chapters to be rewritten is Chapter 23, "Concepts in Shock Data Analysis", which was originally written by Sheldon Rubin who is no longer active in this area. We intend to re-title this chapter "Shock Data Analysis Procedures". The emphasis in the chapter will still be on the shock response spectrum (SRS), but we also want to cover such things as the energy spectrum and temporal moments. After considering various current authorities on the subject, I have decided that you or David Smallwood are the best qualified to take on this task. David is already the author of the chapter on Vibration Testing Machines, so to achieve diversity, I would like to invite you to write this chapter on Shock Testing Procedures. Note that our time line is for a draft of the chapter by the end of this year. If you are interested, please let me know at your earliest convenience, and I will send you the McGraw-Hill Author's Instructions and a detailed outline for exactly what we want to see in this chapter.

I hope to hear from you soon and further hope all is going well for you and your family.

Allan Piersol

From: Alf Olsson [mailto:alf.olsson@elstandard.se]

Sent: den 15 juni 2007 21:48

To: Noeremark, Anders I415

Subject: SVIB, API och nu Möte i Orlando med SC 2/WG 1

Hur gick det för dig i USA. Ylva och jag höll ställningarna i Prag eftersom du inte kunde vara med.

Hälsningar

Alf Olsson

Från: Noeremark, Anders I415 [anders.noremark@siemens.com]

Skickat: den 19 juni 2007 10:44

Till: Alf Olsson

Ämne: RE: SVIB, API och nu Möte i Orlando med SC 2/WG 1

Hej Alf.

Jag tycker att det gick bra. Jag var nästan ensam om att ha gjort det vi kommit överens om d.v.s. tagit fram förslag till de avsnitt som vi fått ansvaret för och det betydde att jag fick mig tilldelat en hel del tid för att presentera mitt . Jag har ansvar för att ta fram förslag till avsnitten balansering och vibrationer och som du vet så försöker jag använda innehållet i våra ISO standarder så mycket som möjligt. Jag tycker att responsen för detta har varit huvudsakligen positiv men det finns ju förstås en del som tycker att man inte skall ändra på det som varit. Förra veckan hade vi arbetsgruppsmöte i Houston och i september blir det stort möte i San Antonio och det blir väl först i september jag verkligen får reda på hur reaktionen blir på de nya förslagen.

MVH

Anders

Från: SEK

Skickat: den 20 april 2007 14:32

Till: olsson@sekom.se

Ämne: SEK byter namn och logotyp

För att tydliggöra vår verksamhet med internationell och nationell standardisering byter vi namn till **SEK Svensk Elstandard**. I samband med namnbytet byter vi också logotyp. Beslut om namnbytet fattades vid SEKs fullmäktigemöte den 19 april 2007.

Vid kontakt med oss gäller nu vår nya internetdomän www.elstandard.se och dokumentserver <https://domino.elstandard.se/>. Våra e-postadresser är fornamn.efternamn@elstandard.se. Den gamla domänen (www.sekom.se) kommer dock att fungera under en lång tid framöver.

Med vänlig hälsning

SEK Svensk Elstandard

SVIB Vibrationsdagen 2007

22 november i Köpenhamn
Gammel Dok, Dansk Arkitektur Center,
Christianshavn.
Anmälan per Internet www.svib.se

2nd American Conference on Human Vibration

Greetings!

Time is speeding by and we are writing to inform you that preparations for the 2nd American Conference on Human Vibration (ACHV) next June 4-6 are in full swing. The conference site will be the Hyatt convention center in downtown Chicago. As with the first, the 2nd ACHV will be a 3-day event. We encourage you to begin working

on your abstract submissions, which again, will be kept to a two-page limit. Details about the conference and abstract formatting will follow soon.

Sincerely,

Farid Amirouche

Alan G. Mayton

Alan G. Mayton, C.M.S.P., P.E.

Lead Research Engineer

National Institute for Occupational
Safety and Health

Pittsburgh Research Laboratory

626 Cochrans Mill Road

P.O. Box 18070

Pittsburgh, PA 15236

<http://www.cdc.gov/niosh/mining>

E-MAIL: amayton@cdc.gov

42nd UK Conference on Human Responses to Vibration 10th – 12th September 2007

Hosted by

Human Factors Research Unit

Institute of Sound and Vibration Research

University of Southampton

I am pleased to invite you to the 42nd UK Conference on human responses to vibration to be hosted by the Institute of Sound and Vibration Research from 10th to 12th September 2007.

Conference information is available at:
<http://www.humanvibration.com/UK2007.htm>

Deadlines:

Titles and outline summaries

– 1st May 2007

Reserving accommodation at Chilworth Manor – 14th May 2007

Full text of papers – 1st August 2007

Conference booking – 1st August 2007

AU1 symposiet på Dunkers kulturhus i Helsingborg

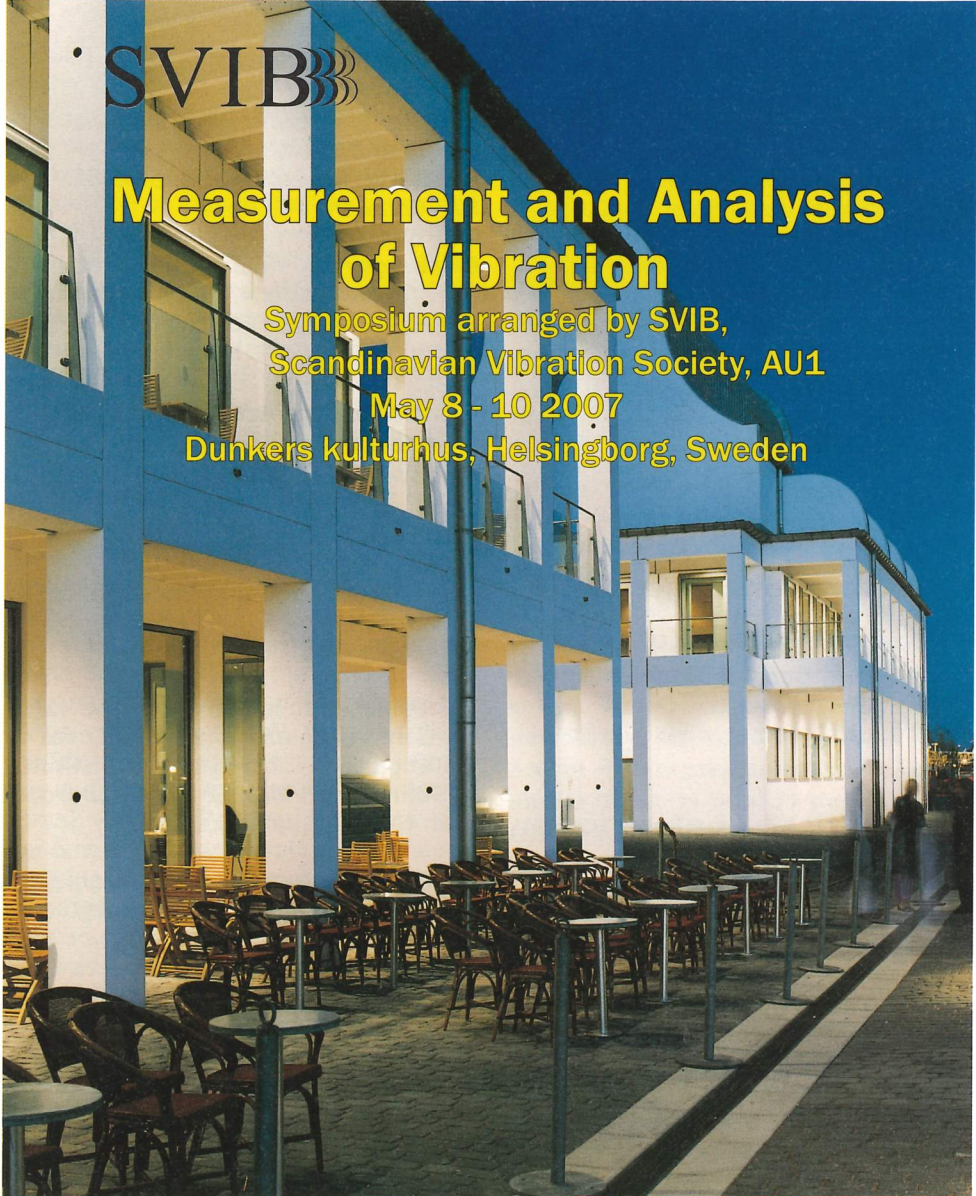
SVIB

Measurement and Analysis of Vibration

Symposium arranged by SVIB,
Scandinavian Vibration Society, AU1

May 8 - 10 2007

Dunkers kulturhus, Helsingborg, Sweden



Nu förestår Vibrationsdagen i Köpenhamn onsdagen den 22 november 2007 men Då i mitten av maj var det fortfarande AU 1 symposiet på Dunkers kulturhus i Helsingborg som gällde. Det får nog anses vara en prestation att få ihop till 50 deltagare varav 8 utställare under den tid på året då det finns så mycket annat som måste hinnas med mellan Valborg- och Kristihimmelsfärdshelgerna.

Mötesplatsen, Helsingborg, hade valts för att underlätta för våra danska vänner att delta. Ett par av föredragshållarna från andra sidan sundet hade hoppat av förra gången SVIB AU 1 inbjöd till special-symposium vid riksgränsen när dom fick klart för sig vart utmed Sveriges långa gräns som AU 1 den gången hade tänkte hålla möte. Den aktuella riksgränsen passade den här gången lite bättre. Ytterligare en omständighet som gjorde att AU 1 symposiet på Dunkers får räknas in bland de små underverken är att alla föreföll vara nöjda både med föredragen och arrangemanget.

"Tutorial sessions"

Ett framgångsrikt koncept från tidigare AU 1 övningar togs åter i bruk på Dunkerssymposiet som inleddes med två parallella sessioner "Lessons learned from developing the ARTEMIS software and dealing with real customer problems" med Rune Brincker från Aalborg University som sessionsledare och Kjell Ahlins uppdrag att utforska nya världar som få har besökt förut under rubriken "Nonlinear Systems – The Final Frontier". Kjell återkom senare med flera föredrag med anknytning till Blekinge Tekniska Högskola men också till Axiom edutech som han sen en tid återknutit kontakten med sen han lämnat

högskolan. Hans föredrag "On the Comparison of Test Specification and Measured Field Data" återges i detta eller kommande nummer av SVIB Nytt.

På kvällen åt vi middagsbuffé ombord på färjan AURORA under några timmars färd över sundet.

Annars var det mycket Active noise och Vibrationsövervakning på programmet. Thomas Lagö, Acticut International inledde med "ANVC Methods and Applications in a Historical Perspective" och Urban Emborg, A2 Acoustics fyllde på med "Active Noise Control in a Passenger Car". Båda dessa föredrag återges i SVIB Nytt.

Leif Norman, Physical Acoustics Scandinavia beskrev och demonstrerade olika användningssätt och hur han kalibrerade utrustningen för akustisk emission genom att bryta av ett blyertsstift. Richard Lax, m+p International,



Richard Lax, m+p International

förespråkade användningen av PC baserade FFT Analysatorer och Markku Juntunen, VTT gick loss på ämnet "Simulated Shock Loads".

Whiskeyflaskan - förstapriset för bästa företagspresentation gick till Thomas Eriks-son, Proxitron AB.



Thomas Eriksson i samspråk med Göran Jonasson

Pärmen med föredragen är verkligen fullspäckad och vi har redan sålt och levererat flera exemplar. Vi tar 500 kr för alla föredragen utskrivna och insatta. Vi har fortfarande några pärmar kvar i lager. Beställer ni pärmen så får ni veta hur man skriver vibrations specifikationer av Jörgen Svensson, Hur man sköter vibrations övervakning av Elisabet Blom, vilka åtgärder Claes Fredö anser nödvändiga för övervakning av vibrationer i rörssystem och hur trion Lagö, Brandt, Lindberg blandar gammalt och nytt med analog och digital omvandling och senare "What is it, Really - Source Ranking?"

I Semcons monter fanns Lars Ivarsson och han höll ett föredrag om "Transfer Path Analysis for a Diesel Engine Installation" och i ÅF-Ingemansson monter fanns Bengt Johansson,



ÅF-Ingemansson monter fanns Bengt Johansson

Romain Haettel som också talade om "Measurement and Prediction of Structure-borne Sound in a Building above the Subway"



Ramin Ghalehie

Kjell Vågfeldt från ÅF-Ingemansson hade sammanställt en översikt över vibration-problem i kärnkraftverk.

Dan Maguire, Cooper Standard Automotive, som kom i sällskap med kvartetten från Acticut, uttalade sin stora tillfredsställelse med arrangemanget och höll ett längre föredrag om "Active Control in Production".



Dan Maguire, Cooper Standard Automotive,

Två föredrag hamnade på restlistan när föredragshållarna hade fått förhinder. "Vibrations from Big Diesel Engine" Patrik Nordberg. ÅF-Ingemansson AB och "Effects of and Coping with Non-linear Sensors Characteristics" Ole Dossing, Roving Dynamic A/S

DINNER WITH HAPPENING

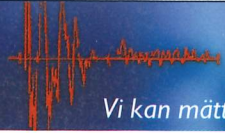
Så stod de i programmet. Det gick inte att utlova något specifikt eftersom det in i det sista var oklart hur många deltagare det skulle bli och därmed vilken budget som kunde anslås till underhållning. Men vad vore ett SVIB symposium utan sång och musik.

I souvenirbutiken på Dunker sålde flickan Tretorn galoscher, numera tillverkade i Kina. Hennes sambo är en enastående duktig Blues sångare och även om han hade varit lite avvaktande till mina idéer om att några av deltagarna kunde tänkas vilja delta i underhållningen efter att han genomfört sitt program

så blev det faktiskt så. Per Lindberg satte sig vid pianot, och Jörgen Svensson greppade en av gitarrerna och vi andra ställde oss i ring och sjöng med i Gräsänklingsblues och några av dom oförglömliga skiffel-låtarna. Det blev på det hela taget en glad afton och en riktig happening såsom utlovats.



Per Lindberg satte sig vid pianot, och Jörgen Svensson greppade en av gitarrerna



Vi kan mätteknik

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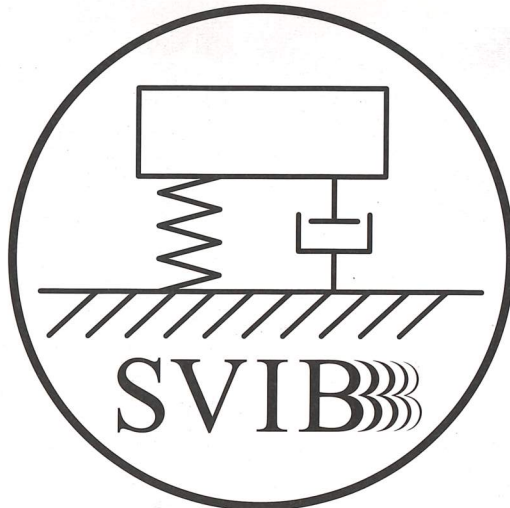
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