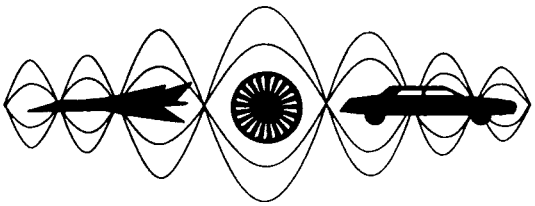

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INDUSTRIALIZATION OF ACTIVE CONTROL TECHNOLOGIES

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ABSTRACT

Industrialization of active control technologies is a specific trade. This new technology is not completely controlled. Several specific competences are necessary. In this paper we present a synthesis on the limitation of active control technologies, advantages, application estate, development and industrialization's tools. The second part of the document presents products using this technology.

INTRODUCTION

Active noise and vibration control is a new technology which demands to the acoustics and mechanics specialists to learn new abilities : electroacoustics, signal processing and electronics. This technology can be theoretically applied in several domains. Research works on this subject are more and more numerous. Although this technology is not stabilised and fully controlled. We proposed in this paper to present a state of art about industrialization of active control technologies : domains , difficulties, development and products' tools.

I - APPLICATION DOMAINS

When can we use active control ?

The predilection domains of active control are the following : acoustics, vibroacoustics, vibromechanics and fluids mechanics. The first domain historically explored was acoustics. But rapidly active control appeared a good solution for the other domains. Each one asks to the active control specialists to undertake specifications on physics value of this application, environment conditions, actuators and sensors technologies.

The typical kind of noises which can be controlled, can be repetitive noise with pure tones but also wide band noise, random noise. The attenuation amplitude depends on several parameters. As a pure tone can be drastically reduced 60 dB as shown on Fig 1, a reduction of 20 dB on wide band noise is noticeable.

Physical problems concerned can be one, two or three dimensional.
Small acoustic cavity and vibrations beam are considered as monodimensional problem, and were subject to many research and development works [1],[2]. Today active noise control in small cavity is produced in high series for individual protections.
Active control is also used for two dimensional problems. Especially in propagation guide and for plate vibrations [3]. Products had been developed with active control for ventilation noise reduction.
For three dimensional problem, some active control solutions can be proposed. Sometimes, in great volume, a global treatment is possible. When the noise source can be localised, active control can be used to improve the enclosure insulation.

Active control instead of passive solution ?

No, the active control is not a solution which could be used instead of passive one. Active control and passive solutions are complementary.
The passive solutions' performances are limited in low frequencies. Active control is able to treat these low frequencies. Moreover, the product definition is the choice of the best compromise between the two kind of treatments.

II - ACTIVE CONTROL TECHNOLOGY USED IN INDUSTRIAL PRODUCT

Limitation of active control

The limitation of active control are physical and technological. For the physical one, usually the wave length and the geometry are the principal limitations.

The calculator speed, the number of transducers and the secondary sources' power are the principal technological limitations.

Technical-economical advantages

The advantages of an active control solution are different for each case. The usual advantages in comparison with a passive solution are a weight, a volume and an energy saving. An active solution allows an optimization for definition, dimension and installations and gives a complete frequency range treatment.

Is it applicable to each product

Theoretically active control can be applied to all product, but in a particular point of view, there are limitations. The secondary sources, radiation and acoustic power, are the main limitations for the active control application on each product.

III - FROM RESEARCH TO DEVELOPMENT

Technologies carry into effect

Concerning transducers, different types are used. In most cases, there are loudspeaker, piezoelectric film or shaker. The sensors can be microphones, accelerometers or piezoelectric film...

The controller can be analogic or numeric. And two kind of controls can be used direct filtration (feedback) or feedback filtration.

Difficulty for the laboratory-industry transfer

Different cultures between laboratory and product manufactures make the transfer between laboratory and industry not easy. The relations between researchers and industrials had to be carried out carefully. As it is necessary to develop all results of research, it is essential to be sure that the product will reply to a market need and will not be only a super prototype.

That is why it is helpful to deal with a company specialized in active control production, instead of classical study office.

The product industrialization with active control can be difficult because of technological novelty it uses. The need of an interdisciplinary combination for the development of such product, may sometimes slow down this development.

The marketing is often disturbed by the comparison between the active product prices and the classical product.

The heavy installation and maintenance for some products which were badly industrialized, completely perturb the marketing way.

Product for development help

The products used for an active control product development, are software (as Matlab for instance), PC cards (Analog Device, Texas inst...), controllers associated to a PC (EZ-kit from Analog Device monochannel equipment, EZ-ANC from Causal/TechnoFirst® [4] multichannel equipment).

Integrated controllers are proposed : multichannel with a PC link (Digisonix) or multichannel with or without P.C.link (NOVACS TechnoFirst®).

TechnoFirst® proposes now a new generation of controller called the NOVACS Hybrid [5]. This product was developed in order to combine the two types of control : feedback and feedforward. This combination is really an hybridisation. The system structure was chosen in order to keep advantages of each type of control and to cancel their drawbacks.

Three type of control proposed by TechnoFirst®

Active noise control and active vibration suppression can be separated into two broad control strategies : feedforward and feedback control.

Feedforward can be applied if a reference signal correlated to the disturbance is available; the reference signal is passed into an array of adaptive FIR digital filters, and applied to secondary sources in order to minimize an error signal from appropriate sensors. The coefficients are adapted with a multichannel Least Mean Square (LMS) algorithm called "x-Filtered LMS" in SISO configuration.

The algorithm involves a large amount of real time computation which can be handled adequately by current DSP chips. Feedforward control has been applied successfully to the cancellation of narrow band disturbances, even with very short FIR filters. It also works for wide-band disturbances but longer filters are necessary.

The method does not need a precise model of the system, but only an estimate of the impulse response. Although it is fairly robust with respect to the truncation of the impulse response, the amount of computation involved in estimating the model response increases significantly for lightly damped vibrating structure, reducing the bandwidth where the feedforward acts effectively.

Feedforward control is essentially a local method in the sense that for wide-band applications where many modes may be involved, the response to the disturbance cannot, in general, be reduced uniformely over the entire domain; low amplitude response near the error sensor may be obtained at the expense of amplified ones in other parts of the system.

Feedback can also be used for noise and vibration control. If the objective is to reduce the resonant peaks in the transfer function and the settling time to transient perturbations, the feedback loop acts; it is often referred as *Low Authority Control (LAC)*. These compensators have simple forms and can be implemented either in analog or digital controllers.

Note that some of them consist of second order filters which must be tuned on the targeted physics caracteristics; although the stability is guaranteed, the performance of the closed-loop system depends critically on the tuning of the filter parameters on the physics systems.

TechnoFirst® propose a third type of control, **Hybrid control** [12]:
We propose a combinaison between feedback and feedforward
The synergy between the two types of controllers is pointed out. The feedforward control extends the bandwidth of the controller for steady state disturbances with a correlated reference, while the feedback control reduces drastically the impulse response of lightly damped structures, avoiding the problems associated with truncation. The Hybrid NOVACS™ controller does not require additional actuator and sensor. In each example presented the theoritical advantage of the hybrid controller is confirmed by experiments.
The feedback control allows a very fast control even for an impulse noise. The transfer function between the transducers is measured throught the existing feedback control. The result is a shorter impulse response, and means less datas and time computing for the feedforward system. This has been pointed out in the vibration suppression application.
The precision pointing and the ANC applications show that feedforward control can deal with stationnary disturbances which are outside the bandwidth of a model-based feedback controller, and more generally over a wide range of frequency, limited only by the sampling period and the hardware available.
The hybrid control can be used whenever the system is subjected to impulsive and stationnary disturbances provided that a reference correlated to the disturbance is available; there is no detrimental interaction between feedback and feedforward, and they can be used with the same set of actuators and sensors.

IV - PRESENT AND FUTURE PRODUCTS

Individual protections

This product was the first active control product marketed.
The individual protection is composed of two cups, which assure the passive reduction. In each cup is introduced a microphone, a speaker and an electronic.

Existing products are presented here :

- Military headsets are proposed by companies such as Bose, Racal and TechnoFirst®.
- Civil aviation headsets are offered by Bose, Telex and TechnoFirst.
- Industrial headsets were the first great series producted on the market in 1989, and proposed by TechnoFirst®.
- The last product is a general public headset proposed by Sennheiser and TechnoFirst®.

On fig. 1and 2 the headset series of TechnoFirst® are presented.

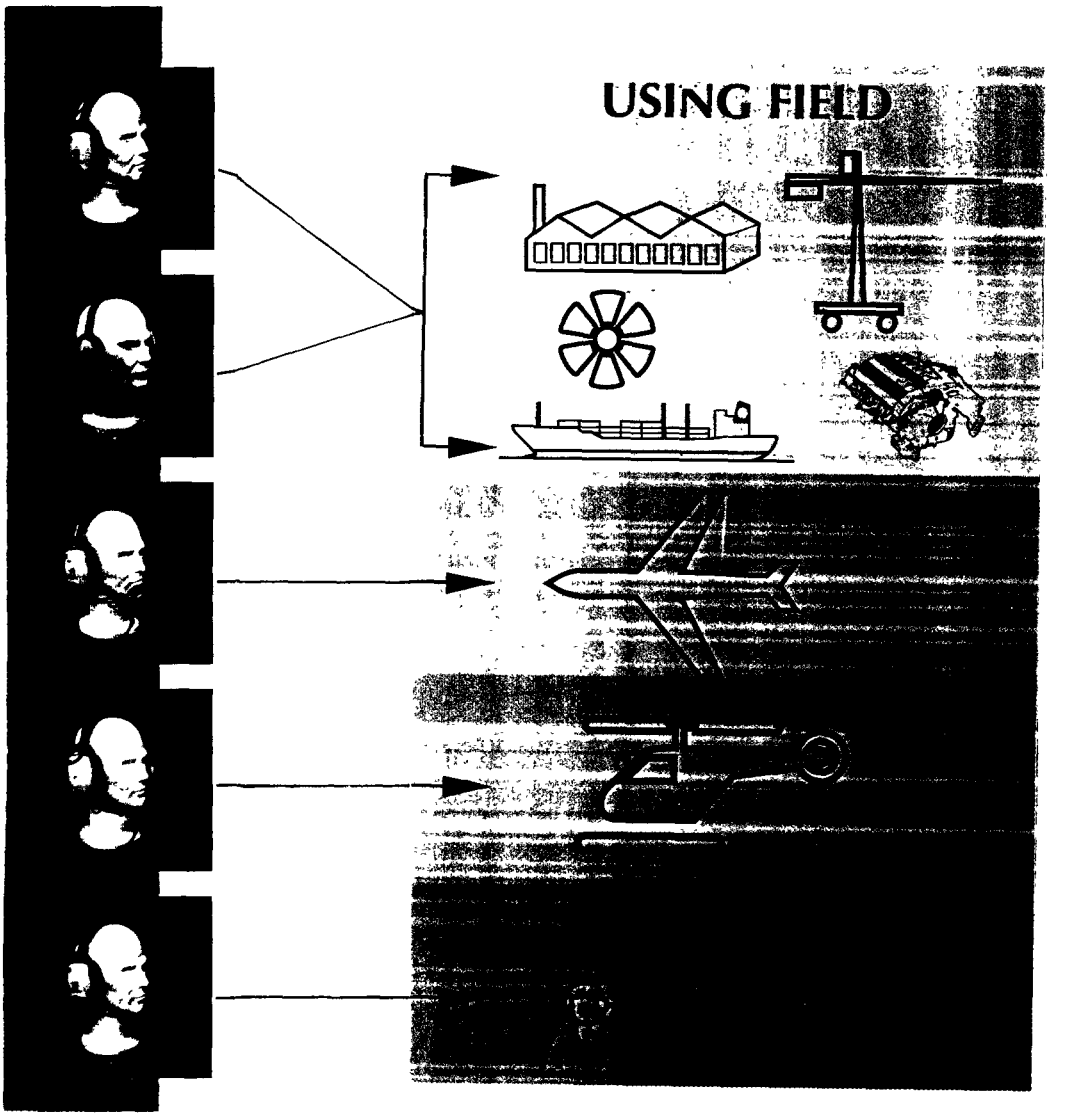

Fig. 1 : Headsets series with communication

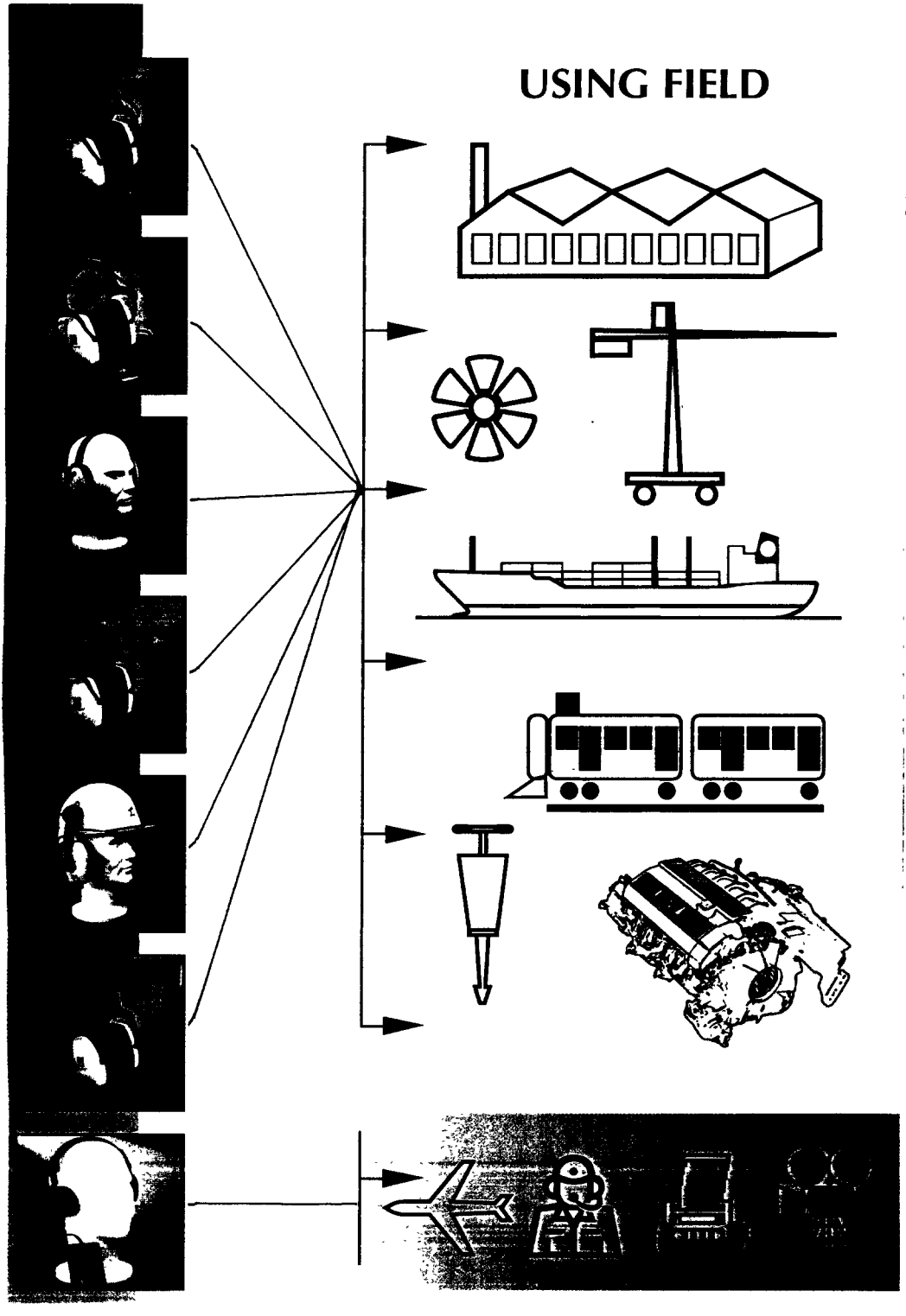

Fig. 2 : Headsets series without communication

Muffler for ventilation duct

Two different products exist on the market.
An active system without passive element and which had to be installed and calibrated by the manufacturer. This product is called **Motus** and is proposed by Carrier and Digisonix.
The second product is a combined active/passive product which can be installed by the user and which is autocalibrated. This product is proposed by TechnoFirst® and his partner Aldes aeraulique [6] and is called **ACTA™.**
It was installed on several places, on fig. 3 is presented a plan installation in a French school.

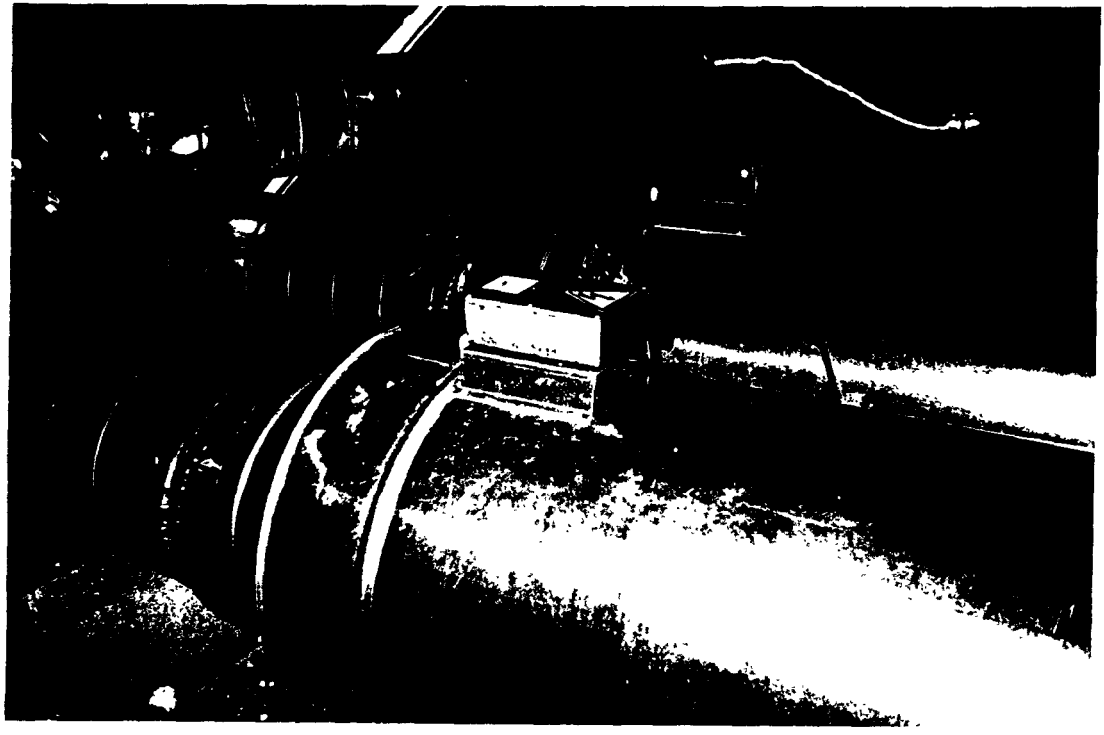

Fig. 3 : ACTA™ : two products in a ventilation system

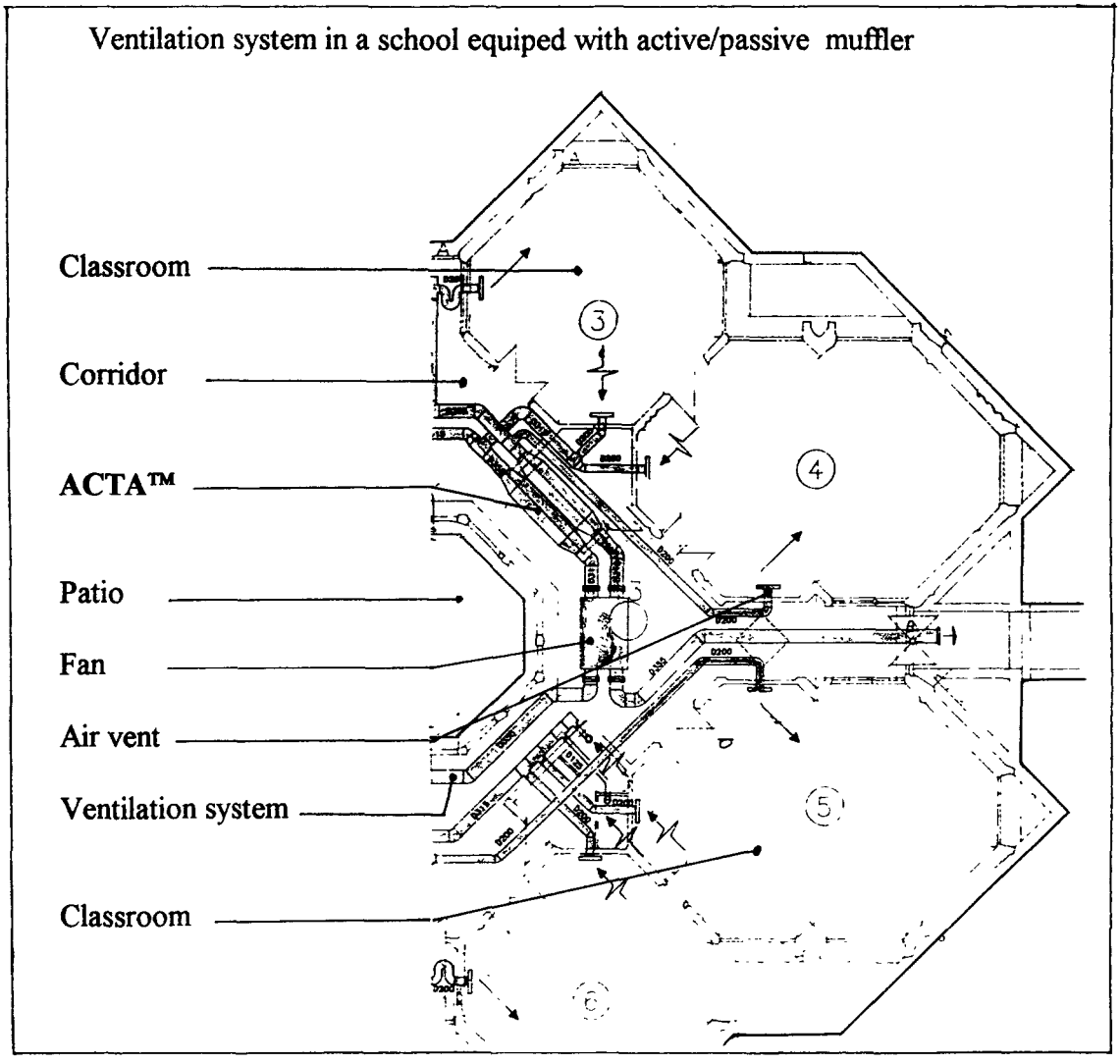

Fig. 4 : Ventilation system equiped with ACTA™

Another product is in fast-developing for the subway ventilation in Paris [7], for a very large diameter. The aim is to make an acoustic/economical and aeraulic optimisation of the ventilation system. The reduction of the ventilation size duct will reduce drastically the prices The active/passive muffler will allow to reduce noise in this new flow speed conditions. A first demonstration in an existing place was made. A multichannel (6) active noise reduction system was installed in the duct, in addition to the existing passive mufflers. The active system reduced completely a pure tone at 200 Hz at the exit of the duct. This attenuation was eared in the street near the airvent.
On fig 5 is represented the active system installation in the duct.

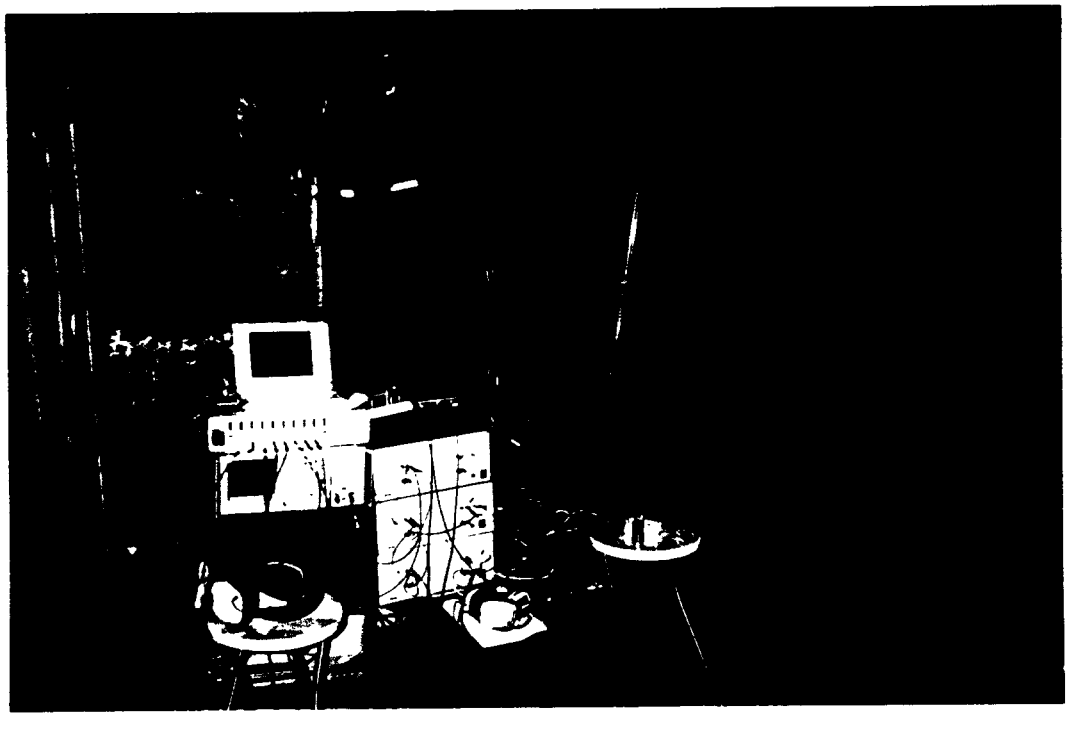

Fig. 5 : Demonstration of multichannel active control system in subway in Paris

Cabin active noise treatment

Two type of active system are proposed : a global or a local approach.
The global solution was proposed by several companies : Ultra, Lord, Gec-Marconi.[8]
The local solution is proposed in partnership by TechnoFirst® and Dassault Electronique : **ANCAS™** is introduced in a headrest [9] and creates a silence area around the head passenger. This product is in way of qualification and certification and will be produced at the beginning of 1998.

Fig. 6 : ANCAS™

Active double glazing

This product is in way to be industrialized [10]. The active part allows to improve the double window insulation in low frequencies, without having an important weight. It is composed by loudspeaker and microphones inserted in the air volume and invisible. Once again is an original's TechnoFirst® transducer which helps to reach a good solution.
Fig. 7 represents a product prototype. This product will be industrialized in 1998.

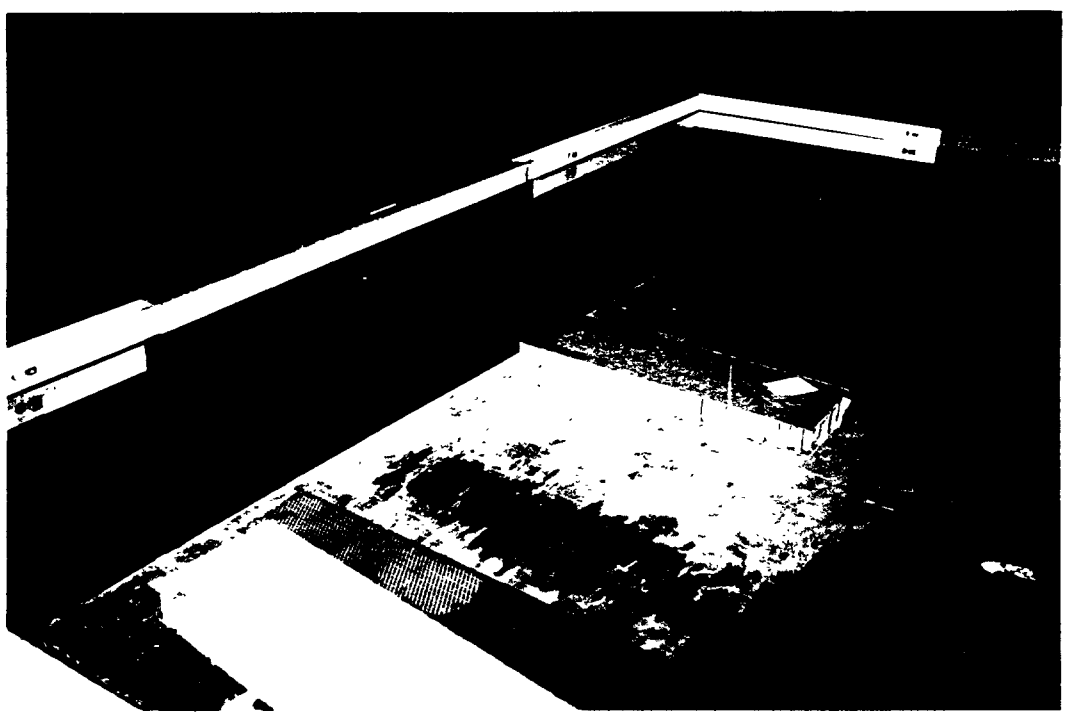

Fig. 7 : Prototype of active double glazing

Vibrations treatment

Some active shakers are proposed by Lord Corporation.
An active/rubbery support, called VIBRATIS [11] was developed in partnership by Paulstra-Hutchinson and TechnoFisrt®.
Fig. 8 represents a prototype of the system.

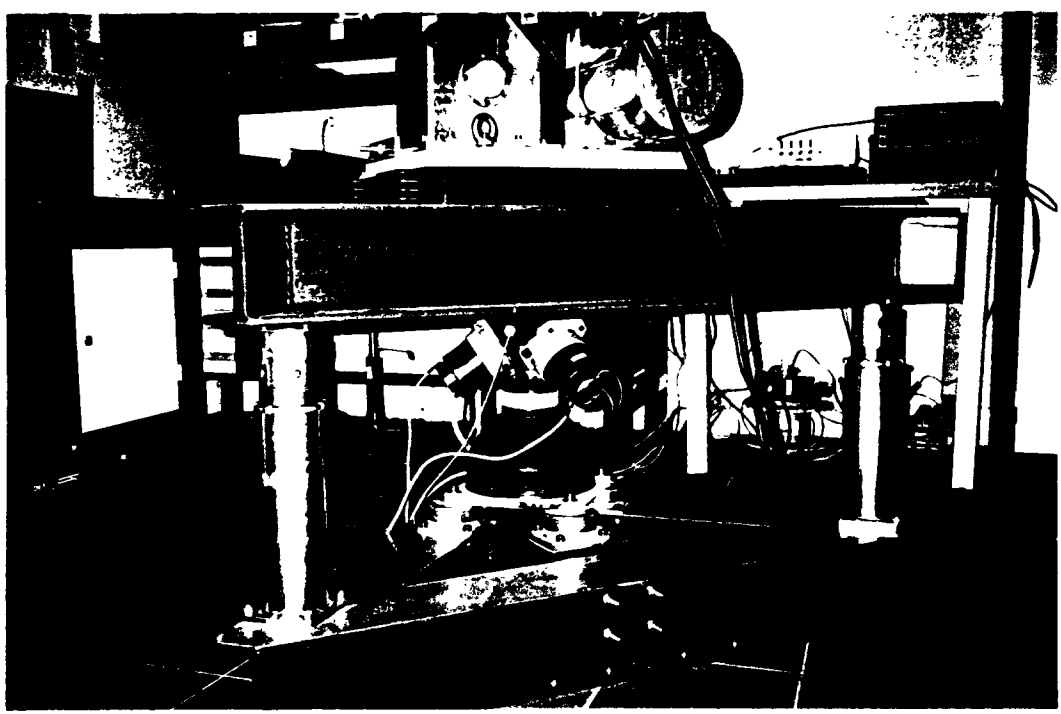

Fig. 8 : VIBRATIS

CONCLUSION

Today we are only at the beginning of active control technology. application.
Product industrialization using this new technology requires several competences. Not only scientific competences such as acoustics, mechanics, electronics and signal treatment, but also specific abilities for the technological transfer between the laboratories and industry. That is why we say that industrialization of such a product is a specific trade. This trade consists in the choice of laboratories concept able to become a product, the market choice and the industrial partner introduced in this market. Moreover this trade consists in the choice of the best compromise between passive and active elements in comparison with the performances and economy arguments.
TechnoFirst® company has chosen this trade since 1987. We are working with French laboratories and industrial partnerz on several industrialisation projects. With our partners, we achieve the development, the industrialisation and the manufacture of several active noise and vibration control systems adapted to our customers products and in addition to traditional insulation.

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