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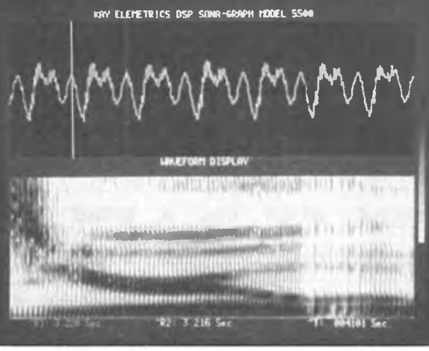
EDITORIAL

Au mois d'août 1988 à Stockholm , les spécialistes du monde entier se sont réunis, comme c'est prévu à tous les cinq ans, pour faire le point sur la recherche concernant les effets du bruit. Pendant que se tenaient ces assises sur "le bruit comme problème de santé publique", des dizaines de vendeurs sur les places du centre-ville de Stockholm faisaient la promotion d'un nouveau jouet sonore en provenance de Taiwan, des boules détonantes. Il s'agit de deux billes qui, lorsque heurtées l'une contre l'autre, génrèrent une explosion de large spectre, riche en hautes fréquences et dont le niveau de pression acoustique de crête atteint 140 dB (re 20µPa) à un mètre. Etant donné le caractère insidieux des effets du bruit, on peut s'attendre à ce que ce type de jouet fasse l'objet de communications scientifiques lors du prochain congrès quinquennal... (qui pourrait d'ailleurs avoir lieu à Taiwan). En effet, puisque les lésions de l'oreille interne ne sont pas visibles pour les gens en gěnéral, et puisque les pertes d'audition causées par le bruit se ne sont pas facilement identifiées du moins à ses premiers stades, les jouets sonores, comme les autres sources de bruits nocifs, ne sont généralement pas reconnus comme des sources de danger pour la santé. Au Canada, il n'y a, à toutes fins utiles, pas de disposition rěglementaire pour limiter le bruit des jouets qui produisent des détonations. Par chance, la version des boules détonantes que l'on trouve sur le marché canadien est moins bruyante (134 dB crête à 1 mètre, avec un maximum d'énergie autour de 3 kHz toutefois); mais elle constitue certainement une source de danger pour l'audition des enfants qui l'utilisent d'autant plus qu'il est très facile de les déclencher à proximité de l'oreille. Doit-on attendre que les victimes soient suffisamment nombreuses pour qu'il vaille la peine d'entreprendre une étude épidémiologique dont les résultats pourraient aider à convaincre du bien-fondé d'une règlementation en la matière? Par une sensibilisation de la population, les professionnels de l'acoustique auraient peut-être une plus grande influence à plus court terme.

In August 1988, specialists from all over the world met in Stockholm, as happens every five years, to discuss the state of the art of research on the effects of noise. At the same time that this conference on "Noise as a Public Health Problem" was being held, dozens of street salesmen of downtown Stockholm were offering a new sound toy from Taiwan, explosive balls. These consist of two small rigid balls which produce an explosion when they hit one another. The sound, which has a broad spectrum with energy concentrated in the high frequencies, reaches a peak level of 140 dB (re 20µPa) at one meter. In view of the insidious character of the effects of noise, it can be expected that this type of toy will be the subject of scientific papers in the next five yearly conference... (which we suggest be held in Taiwan). Since damage to the inner ear is not visible to people in general, and that noise-induced hearing ioss is difficult to recognize in its early stages, sound toys, as other noxious noise sources, are not easily recognised as sources of danger to health. In Canada, practically speaking, there are no legal provisions to limit the noise from explosive sound toys. Luckilly, the version of the explosive balls that are available on the canadian market is less noisy (134 dB peak at one meter, although with a maximum of energy concentrated around 3 kHz); nevertheless, it is certainly a source of danger for the hearing of children who use them, all the more so since they are easily activated near the ear. Do we need to wait until the victims are sufficiently numerous before it becomes worhtwhile undertaking an epidemiological study , the results of which could help to convince people of the need for an adequate regulation? By making people more sensitive to the problem, professionals in acoustics could possibly have more influence in the short-term.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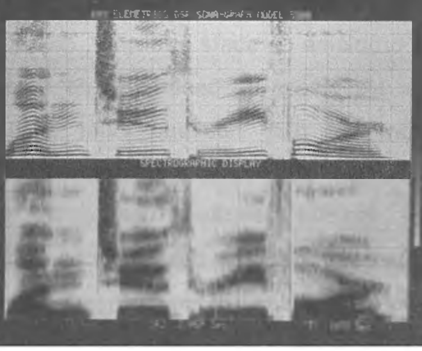
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1988 Update on Regulating Occupational Exposure to Noise

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SOMMAIRE

L'article est une mise à jour du texte paru antérieurement intitulé "Regulating Occupational Exposure to Noise" (1). Y sont décrits les travaux menés récemment au Canada en matière de règlements et de lignes directrices concernant l'exposition professionnelle au bruit, ainsi que les documents sur lesquelles ils s'appuyent. Un sommaire des règlements en vigueur et proposés, et des lignes directrices est présenté en dégageant les principales limites d'exposition et les mesures de contrôle du bruit. Les procédures d'évaluation de la perte d'audition pour fins d'indemnisation de la surdité professionnelle sont également résumées.

ABSTRACT

An update is provided to the review paper "Regulating Occupational Exposure to Noise" (1). Recent Canadian activities concerning occupational noise standards, guidelines, and background documents are described. A summary of Canadian existing and proposed regulations and voluntary guidelines, are presented, outlining noise limits and other noise control measures. Methods of assessment of compensation for occupational hearing loss are summarized.

1.0 INTRODUCTION

A brief historical background to occupational noise regulations has been given previously by Benwell (1), together with a description of noise "dose-relationships". A more detailed description of exposure to steady and intermittent noise and exposure to impulsive noises is given by Shaw (2,3), who draws on the 2 decades of such research to make general conclusions that help put present occupational noise regulations on a firm scientific base.

The present paper provides an up-to-date (as of July 1988), summary of Canadian occupational noise legislation in the context of other recent activities in the area of occupational noise. Present workers' compensation claims for occupational noise-induced hearing loss in Canada are illustrated. The National Health and Welfare program in occupational noise is outlined. It is recommended that Federal/Provincial Guidelines (4) and the Shaw Report (2) be used in the formulation of new or revised Canadian occupational noise regulations.

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* formally D.A. Benwell

2.0 RECENT ACTIVITIES IN HEARING CONSERVATION

For the last five years effort has been made in Canada to develop uniform national occupational noise standards. This has been aided by an important publication by Shaw clearly delineating the scientific and technical and practical background on the subject (2). ISO DIS 1999.2 (1985), an important international document on occupational noise exposure and noise-induced hearing impairment has also been revised and is in press (5).

2.1 C.S.A. Standards

The Canadian Standards Association (C.S.A.) Committee Z107 on "Acoustics and Noise Control", has been active in the area of hearing conservation standards for a number of years. More recent activities have included the appointment of a Task Force on Occupational Noise. This Task Force conducted a mail survey (1981-82) to some 150 users of standards on occupational noise. Over 60 replies were received, supporting the Task Force recommendation made in 1982 that there was a need for national guidelines on occupational noise and hearing conservation regulations (1).

In recent years, a number of new and revised standards for occupational noise exposure regulations have also been published by C.S.A. The most significant of these is probably the CAN/CSA Z107.56-M86 on occupational noise exposure measurement (6). In addition there are standards on acoustical definitions (7), and on pure tone audiometers for hearing conservation and for screening (8). There is also a draft standard on audiometric testing for hearing conservation purposes (9) and a standard on hearing protectors (10), the latter having been produced by C.S.A. Committee Z94 on Hearing Protectors. In addition international standards for instrumentation (produced by the International Electrotechnical Commission) are used directly (11,12).

2.2 Shaw Report

The Shaw Report (2) was prepared by Edgar Shaw of National Research Council for the Special Advisory Committee on the Ontario Noise Regulation.

The report reviews the scientific evidence, discusses the issues, draws conclusions and presents recommendations within the context of the proposals made by the Ontario Ministry of Labour. The Ontario Ministry of Labour had previously determined that a noise regulation would include: 1) mandatory measurement of noise at and above 80 dBA; 2) the requirement to reduce noise at the workplace to 90 decibels on a time weighted average basis by means of engineering controls, and in case to the lowest practical level; 3) the mandatory use of hearing protection where a worker is exposed to noise that cannot be reduced to 90 decibels on a time weighted average basis or to 85 decibels for 4 hours or more during a work day; 4) the requirement of a hearing conservation program where a worker is exposed to $L_{Aeq4} > 85$ dBA (10).

The Shaw report (2) enables Canadian occupational noise regulations to be put on a firm scientific foundation by drawing on two decades of research and by carefully analyzing and summarizing the results in the context of present day occupational noise problems. The report summary is reproduced below: -

> "In 1983, a Special Advisory Committee was appointed to study and report to the Minister of Labour on several major issues affecting the formulation of a Noise Regulation in the Province of Ontario under the Occupational Health and Safety Act of 1980. This report, prepared for the Committee, reviews the scientific evidence, discusses the issues, draws conclusions and presents recommendations. Exposure to steady and intermittent noise is considered in relation to the total energy theory, the principle of equinocivity, the CHABA damage risk contours based on studies of temporary threshold shift, the "5 dB rule", Ward's laboratory experiments with animals, and industrial epidemiology with particular reference to Passchier-Vermeer's work. Impulsive noise is considered in relation to the CHABA criterion of 1968, the concept of critical level, the energy principle, industrial epidemiology, interaction with steady noise and instrumentation. It is concluded that there is adequate scientific support for the acceptance of equivalent continuous A-weighted sound pressure level (the "3 dB rule"), as defined in ISO/R1999-1984, as the best available measure of sound exposure, that this measure is approximate and cannot at present be refined, that there is at present no scientifically acceptable alternative measure and that no distinction should be made between impulsive and other types of noise. Various hypothetical patterns of sound exposure other than the standard work week are considered in relation to industrial epidemiology, the formulation of permanent threshold shift given in ISO/R1999-1984 and studies of recovery from temporary threshold shift following prolonged exposure to steady noise. It is concluded that the 40 hour work week is acceptable as the integration period provided that an upper limit is placed on the daily duration of exposure and a lower limit on the duration of effective quiet between exposures. Specific recommendations pertaining to mandatory hearing protection, engineering controls, hearing conservation, hearing protector performance and ceiling level are presented within the context of decisions already made by the Ontario Ministry of Labour."

The Shaw report was incorporated in the final report of the Special Advisory Committee on the Ontario Noise Regulation which was published in December 1985 (3). The report of the Special Advisory Committee contains three conclusions and five recommendations.

The conclusions state the following: (i) the 3dB exchange rate be accepted for the measurement of noise; (ii) all noise should be included in one comprehensive measurement; and (iii) the 40 hour work week is an acceptable integration time. All of these conclusions contain certain provisions. Measurements are referenced to a revised international standards document, ISO/DIS 1999-1984. This document, (see Section 2.0) was subsequently reissued for voting as ISO/DIS 1999.2 (1985) and is presently in press to be issued as a full standard ISO 1999 (198x) (5).

The recommendations of the Special Advisory Committee, in response to the specific terms of reference received from the Ontario Ministry of Labour, are that the use of hearing protectors should be mandatory where the noise level $L_{Aeq8} \geq$ 85 dBA and that a programme of education and instruction be provided; engineering controls be required when $L_{Aeq40} \geq$ 90 dBA; a hearing conservation programme with periodic audiometry be required when $L_{Aeq40} \geq$ 85 dBA; CSA Standard Z94.2-M1984 be recognized for the assessment of hearing protector performance; and that the use of hearing protectors be mandatory where there is exposure to occupational noise with instantaneous peak sound pressures exceeding 200 Pa (140 dB relative to 20 μPa). It should be noted that the 40 hour work week is accepted as the integration period for the development of engineering control and for hearing conservation with periodic audiometry subject to special provision being made for the unconditional distribution of hours within the work week. For details regarding the provisos accompanying these conclusions and recommendations the Special Advisory Committee Report should be consulted (3).

2.3 Federal/Provincial Guidelines

In 1982 the Federal/Provincial Advisory Committee on Environmental and Occupational Health established a Working Group on Occupational Noise Exposure and Hearing Conservation. The terms of reference of this group were to prepare guidelines on occupational noise exposure and hearing conservation regulations. This was done at the direction of the Committee, which was, in part, in response to the results of the Questionnaire circulated by the CSA Task Force described in 2.1. Part 1 of the document is now published (4). It was written to assist provincial and other agencies for provision of an effective level of protection against excessive noise in the workplace; the primary goal being the conservation of workers' hearing. The model regulation in the document may be adopted in its entirety or may be modified to satisfy the specific requirements of the regulatory agency. The use of the document by provincial and other agencies should promote greater uniformity in workplace noise control regulations.

The document provides the framework for an occupational noise exposure and hearing conservation regulation (model regulation), together with Codes of Practice for audiometry, hearing protectors and noise measurements. The rationale for the framework with explanatory notes, indicating alternatives and discussing the various factors under consideration, is given in an Appendix to the document.

A summary of limits and required actions is given in Table 2.1. The model regulation defines noise as sound levels greater than 80 dBA and uses the equivalent sound exposure level (L_{EX}) as the measure of sound (This is similar to L_{Aeq8h}). The Codes reference the appropriate CSA standards where available. L_{EX} is defined as the steady sound level in dBA which, if present in a workplace for 8 hours in one day, would contain the same total acoustic energy as that generated by the actual and varying sound levels including impulse noise to which a worker is taken to be exposed in one day.

SEL ?

TABLE 2.1

FEDERAL/PROVINCIAL GUIDELINES

SUMMARY OF LIMITS AND REQUIRED ACTIONS (4)

LIMITS	REQUIRED ACTION
. Sound level is greater than 80 dBA for a significant period of time.	Screening assessment*
. Exposure level, Lex, greater than 85 dBA (for 8 hours per work day)	Noise measurement Hearing conservation program Voluntary hearing protection Warning signs Audiometric tests Records Worker education
. Exposure level, Lex, greater than 90 dBA (for 8 hours per work day) and/or . Impulse noise, peak sound pressure level greater than 140 dB	Mandatory exposure control - engineering controls - work practices - hearing protection

3.0 SUMMARY OF CANADIAN LEGISLATION

Occupational noise legislation in Canada is for the most part covered by legislation having general health application and promulgated by the individual provinces and the Federal Government. Table 3.1 lists current and proposed occupational noise regulations of wide application in Canada. In some provinces there is specific legislation for industries such as lumbering, mining, construction and forestry. These are listed in Benwell 1983 (1) and in a Labour Canada publication on the subject (13) together with its later updated inserts.

The primary legislation on occupational noise applicable to Federal employees is the Canada Labour Act (1976, Revised in 1984). The Noise Control Regulations contained in the Canada Labour Code under this Act were proclaimed in 1971 and modified in 1973 (14). At present these

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* defined as a methodical examination of the workplace with respect to noise exposure and may or may not include preliminary sound level measurements(4).

TABLE 3.1

CURRENT AND PROPOSED OCCUPATIONAL NOISE REGULATIONS OF WIDE APPLICATION IN CANADA

JURISDICTION (Agency)	REGULATION (Proposed/Guidelines)		YEAR	REFERENCE
Federal Labour Canada	Canada Noise Control Regulations	SOR/71-584 Amended by SOR/73-66 and SOR/76-436	1976	14
Federal Health & Welfare	Treasury Board Guidelines	Noise Control and Hearing Conservation Standard. TB STD 3-12	1978	15
Provincial Alberta	Occupational Health & Safety Act (S.A. August 27) Noise Regulations	Regulation 314/81	1981	17
British Columbia	Workers Compensation Act (SBC1968c59 as amended)			
	Industrial Health & Safety Regulations	BC Reg 585/77	Oct.1 1979	20
Manitoba	Workplace Safety & Health Act (S.M.1976c63) Hearing Conservation and Noise Control Regulation	116/85	Nov. 1985	21
New Brunswick	Occupational Health & Safety Act (SNB1976c0-0-1 as amended) Occupational Safety Code	NB Reg 77-1 amended by NB Reg 77-19 and NB Reg 77-92	1977	24
Newfoundland	Workers' Occupational Health & Safety Act (RSN1979c104)	O.C. 799/77	1979	26
	Occupational Health & Safety Regulations	Section 31(5)		

TABLE 3.1 (continued)

CURRENT AND PROPOSED OCCUPATIONAL NOISE REGULATIONS OF WIDE APPLICATION IN CANADA

JURISDICTION (Agency)	REGULATION (Proposed/Guidelines)		YEAR	REFERENCE
North West Territories	Industrial Safety Regulations Safety Ordinance	RONWT271-77 Sections 32,33	June 1977	28
Nova Scotia	Industrial Safety Act - Industrial Safety Regulations	R.S.N.S. C141 as amended	1967	29
Ontario (existing)	Occupational Health & Safety Act (R.S.O.c321, 1980) Regulations for Industrial Establishments	Ont. Reg. 692/80	1980	33
Ontario (Proposed)	Proposed Regulation under the Occupational Health & Safety Act. Designated Substance - Noise		July 1986	34
Quebec	Environmental Quality Act (SQ1972c49 as amended). Regulation concerning industrial & commercial establishment. Reglement relatifã la qualité du milleu de travail.	O.C.3787-72 as amended by O.C.1576-74, O.C.1958-76 and O.C.3326-76 O.C.3169-79	Jan. 1981	36
Saskatchewan	Occupational Health & Safety Act Section 13 (1981c567/81). The Occupational Health & General Regulations Part IX Noise.	c567/81	Apr.15 1981	40
P.E.I.	Industrial Safety Regs.	Royal Gazette, p.253 as amended.	1975	35
Yukon	Occupational Health & Safety Act. Occupational Noise Regs.	Ch.46	1984	43

Noise Control Regulations are commencing revision and a consensus process is being used whereby labour and management and selected technical experts jointly formulate the regulation, using resource documents of their choice. These noise regulations apply to Federal Works, undertakings, and businesses. Public service departments and agencies are also covered by the Canada Labour Code, but in this case the Treasury Board also administers its own standards. Treasury Board Standards on occupational noise exposure were issued in 1972 and modified in 1978 (15). A draft Treasury Board Standard was written in 1982 (16), but this was not implemented since it was decided to wait until the Labour Canada Noise Regulations were rewritten for consistency within Federal jurisdictions. Approximately 750,000 people are covered by these Federal regulations.

Other occupational noise legislation in Canada (17-43) falls within provincial jurisdiction, and thus applies to the majority of working Canadians.

3.1 Noise Exposure Limits

Limits of noise exposure prescribed in Canadian occupational noise legislation are shown in Table 3.2. It is implicit in these regulations that noise levels are measured in a diffuse sound field with an omnidirectional microphone. It can be seen that there are some differences between the various regulations. The three main differences are: 1) the 85 or 90 dBA for an 8 hour per day exposure, 2) the variation between a 5 dB increase for a halving of exposure time prescribed in most provinces and a 3 dB increase for a halving of exposure time prescribed in some provinces, and 3) combined or separate assessment of impulse noise. A recent trend toward a 3 dB trading relationship is reflected in Manitoba (1985), Yukon (1984), and draft Ontario (1986) legislation. This enables a combined assessment of impulse and steady-state noise. Seven provinces specify a separate assessment for impulse/impact noises that varies with the number of impulses, as shown in Table 3.3. The Canada Labour Code presently prohibits exposure to impact/impulse sound "the peak sound pressure level of which, measured by a method acceptable to the regional safety officer, exceeds 140 dB unless that employee is wearing (prescribed) hearing protectors" (14). Impulse noise limits are not specified by 4 provinces. Impulse noise exposure level measurements are now incorporated with steady-state noise measurement in two regulations, two proposed regulations and the Federal/Provincial Guidelines (1987) (4), considerably simplifying exposure calculations. Maximum impulse noise limits are also set for these four regulations. At present Saskatchewan legislation (1981) specifies that noise levels in excess of 85 dBA be monitored and controlled, and aural protection of workers be required. Details of compliance, including an 85 dBA maximum daily 8 hour exposure level with a 3 dB increase for a halving of exposure time are given in a guide to compliance published by Saskatchewan Labour (41).

3.2 Alternative Noise Protection Measures

A summary of noise protection measures, other than noise exposure limits prescribed in Canadian Occupational Noise Regulations, is provided in Table 3.4.

TABLE 3.2 CURRENT AND PROPOSED OCCUPATIONAL NOISE REGULATIONS OF WIDE APPLICATION IN CANADIAN PROVINCES

(JANUARY 1988)

JURISDICTION / AGENCY	REGULATION OR GUIDELINES OR PROPOSAL	STEADY-STATE NOISE				IMPULSE NOISE		
		40 HOUR WEEK LIMIT (dBA)	8 HOUR/DAY LIMIT[1] (dBA)	EXCHANGE RATE[2] (dB)	MAXIMUM (dBA)[3]	SEPARATE (S) OR COMBINED (C)	MAXIMUM (PEAK)[4] (dB)	DAILY LIMIT ON NUMBER OF IMPULSES
Federal Labour Canada	Regulation		92	5	115	S	140	No
Federal Health & Welfare	Guideline		92	5	115	S	140	No
Alberta	Regulation		85	5	115	S	140	Yes
British Columbia	Regulation		90	3	105	S	140	Yes
Manitoba	Regulation		90	3	115	C	140	No
New Brunswick	Regulation		90	5	115	S	140	Yes
Newfoundland	Regulation		85	5	115	S	140	Yes
North West Territories	Regulation		90	5	—	—	140	No
Nova Scotia	Regulation		85	5	115	S	140	Yes
Ontario (Existing)	Regulation		90	5	115	S	140	Yes
Ontario (Proposed)	Proposal	90	—	3	115	C	140	No
Prince Edward Island	Regulation		Note 6			—	—	
Quebec	Regulation		90	5	115	S	140	Yes

TABLE 3.2 CURRENT AND PROPOSED OCCUPATIONAL NOISE REGULATIONS OF WIDE APPLICATION IN CANADIAN PROVINCES

(JANUARY 1988) (continued)

JURISDICTION / AGENCY	REGULATION OR GUIDELINES OR PROPOSAL	STEADY-STATE NOISE				IMPULSE NOISE		
		40 HOUR WEEK LIMIT (dBA)	8 HOUR/DAY LIMIT[1] (dBA)	EXCHANGE RATE[2] (dB)	MAXIMUM (dBA)[3]	SEPARATE (S) OR COMBINED (S)	MAXIMUM (PEAK)[4] (dB)	DAILY LIMIT ON NUMBER OF IMPULSES
Saskatchewan	Regulation[5]		85	3	—	C	—	No
Yukon	Regulation		85	3	103	S	140	Yes
Federal/Provincial Guidelines	Guidelines		90	3	—	C	140	No

Notes

1. Maximum permissible daily 8 hour time weighted average exposure level Leq (dBA).
2. Time/intensity doubling rate.
3. Maximum permissible hearing level without hearing protection (dBA).
4. Maximum permissible level (dB peak SPL).
5. Details taken from "Noise Regulations - A guide to compliance for occupational health committees, employers and workers", 6M/09/81, Saskatchewan Labour.
6. In Prince Edward Island levels are not specified in the legislation. Federal Labour Canada regulations are followed.

TABLE 3.3 IMPULSE NOISE EXPOSURE LIMIT

Peak Sound Pressure Level (dB)	Maximum Number of Impulses Per Day
120	10,000
130	1,000
140	100
Greater than 140	0

Hearing Protectors

All provinces with occupational noise regulations prescribe hearing protectors under certain conditions. The majority (British Columbia, Manitoba, New Brunswick, Newfoundland, Nova Scotia, Ontario, Prince Edward Island and Quebec), state in general terms, that hearing protectors must be worn when employers are unable to reduce the noise below harmful levels (or the noise limit table indicated in the regulation).

The Federal Government requires the use of hearing protection at noise levels over 90 dBA, as do Manitoba regulations, who also ask for voluntary use at 85 dBA. Saskatchewan regulations, Alberta, and Ontario draft regulations, require hearing protection at noise levels over 85 dBA, as do Nova Scotia draft regulation guidelines (30). Proposed new Federal Treasury Board Standards require hearing protection at noise levels over 84 dBA.

Certain legislation (Federal Government and Quebec) specify that hearing protectors must comply with Canadian Standards Association (C.S.A.), Standard Z.94.2.1965, although only the Federal Government specifies "as amended". New Brunswick legislation specifies that hearing protectors must comply with C.S.A. Standard Z.94.2-1974, as does British Columbia. However, legislation in British Columbia also has a table giving the C.S.A. Standard Class of hearing protector that may be worn in prescribed sound levels as in Table 3.5. Alberta legislation contains a similar table to that in Table 3.5 as does Ontario draft legislation.

The Federal/Provincial Guidelines (4) require that hearing protectors be provided upon request by workers' at noise exposure levels (L_{EX}) greater than 85 dBA for an 8 hour work day, and that they must be worn where noise exposure levels (L_{EX}) $\geq$ 90 dBA for an 8 hour work day. The Code of Practice for Hearing Protectors in these guidelines provides procedures for the selection, fitting, use and maintenance of hearing

TABLE 3.4 NOISE PROTECTION IN PRESENT AND PROPOSED OCCUPATIONAL NOISE REGULATIONS

(JANUARY 1988)

JURISDICTION / AGENCY	NOISE PROTECTION MEASURES							
	HEARING PROTECTORS							
	REQUIRED WHEN OCCUPATIONAL EXPOSURE LIMITS ARE EXCEEDED	MEET CSA STD.[1]	MEET ANSI[2]	AUDIOMETRIC TESTING REQUIRED	WARNING SIGNS REQUIRED	NOISE SURVEY REQUIRED	NOISE & VIBRATION CONTROL REQUIRED	HEARING CONSERVATION PROGRAM
Federal Labour Canada	> 90 dBA or > 140 dB peak SPL	√	—	√ Conditional	√	√	—	—
Federal Health & Welfare (Existing)	> 90 dBA or > 140 dB peak SPL	√	—	√ Conditional	√	√	—	—
Alberta	√	√	—	√	—	—	—	√
British Columbia	Detailed level requirements	√	—	√	√	—	Yes	√
Manitoba	> 85 dBA	—	—	√	√	√	Yes	√
New Brunswick	√	√		No	√	—	—	—
Newfoundland	√	—	—	No	—	—	—	—
North West Territories	√	—	—	No	—	—	—	—
Nova Scotia	√ At discretion of Inspector	—	—	Specifications (included in guidelines)	—	—	—	—

NOTE: 1. CSA Z94.2-M1984 "Hearing Protectors" (10).
2. ANSI S3.19-1984 "Method for the Measurement of Real-Ear Protection of Hearing Protectors and Physical Attenuation of Earmuffs" (44).

TABLE 3.4 NOISE PROTECTION IN PRESENT AND PROPOSED OCCUPATIONAL NOISE REGULATIONS

(JANUARY 1988) (continued)

JURISDICTION / AGENCY	NOISE PROTECTION MEASURES							
	HEARING PROTECTORS							
	REQUIRED WHEN OCCUPATIONAL EXPOSURE LIMITS ARE EXCEEDED	MEET CSA STD.^{1}	MEET ANSI^2	AUDIOMETRIC TESTING REQUIRED	WARNING SIGNS REQUIRED	NOISE SURVEY REQUIRED	NOISE & VIBRATION CONTROL REQUIRED	HEARING CONSERVATION PROGRAM
Ontario (Existing)	✓	—	—	No	✓	—	—	—
Ontario (Proposed)	85 dBA	✓	✓	✓ 85 dBA	—	✓	Yes	✓
Prince Edward Island	✓	—	—	No	—	—	—	—
Quebec	✓	✓		No	—	—	Yes	—
Saskatchewan	≥ 85 dBA	—	—	✓ Recommended	✓	✓	Yes	—
Yukon	✓ 85 dBA	—	—	✓	✓	—	—	✓
Federal/Provincial Guidelines	✓ 85 dBA voluntary ✓ 90 dBA mandatory	✓	✓ modified	✓	✓	✓	—	✓

NOTE: 1. CSA Z94.2-M1984 "Hearing Protectors" (10).
2. ANSI S3.19-1984 "Method for the Measurement of Real-Ear Protection of Hearing Protectors and Physical Attenuation of Earmuffs" (44).

✓ = yes

TABLE 3.5 HEARING PROTECTOR REQUIREMENTS IN B.C. LEGISLATION (20)

C.S.A. STANDARD Z94.2.-M1984 CLASS	SOUND LEVEL dBA (Note 1)
C	85-93
B	94-99
A	Over 100
A	Impulse (Note 2)

Note 1: This is understood to mean steady level (45).
Note 2: This is understood to mean where Impulse Noise exceeds the B.C. Schedule for impact noise where the maximum number of impacts per 24 hour period are given for specified peak sound pressure levels (20, 45).

protectors, education of workers' and posting of warning signs. The Code allows for either CSA Z94.2-M1984 (10) Section A2 and Table A1 of Appendix A or for ANSI methods with a 10 dB correction factor to be used in hearing protector selection (44).

Audiometric Testing

Four provinces, Alberta, British Columbia, Manitoba and Saskatchewan, Yukon specify requirements for audiometric testing (Saskatchewan in their compliance code), as do draft Ontario regulations and Nova Scotia and Federal/Provincial guidelines. In Quebec, medical examinations may be required periodically, while the Federal Government specifies that audiometric tests may be required in certain situations (>84 dBA in Treasury Board Proposed Standard). New Brunswick, Newfoundland, North West Territories, Ontario, Quebec, Prince Edward Island, and the Yukon do not presently require audiometric tests.

Alberta legislation requires establishments with high noise levels to set up a hearing conservation programme which must include audiometric testing. When audiometric testing is required, it may only be conducted by qualified people. In this case the audiograms shall be made available to the Department of Health. Permissible background noise conditions for audiometric testing are specified in the regulations.

British Columbia legislation states that in any area where levels exceed the criteria, the employer is responsible for the establishment and maintenance of a hearing test program. The criteria are: 1) 85 dBA steady noise or 2) an impact noise table as shown in Table 3.6 and at least one worker with an $L_{EX} \geq 90$. Details of when hearing testing should be conducted, by whom, and recording and keeping of the test results are also required.

TABLE 3.6 BRITISH COLUMBIA SCHEDULE FOR IMPACT NOISE LEVELS ABOVE WHICH AUDIOMETRIC TESTING ROUTINELY REQUIRED (20)

PEAK SOUND PRESSURE LEVEL (dB)	MAXIMUM NUMBER OF IMPACTS PER 24 HOUR PERIOD
Over 135	0
134	112
131	225
128	450
125	900
122	1800
119	3600
116	7200
113	14400

Federal/Provincial Guidelines (4) require an audiometric testing programme where noise exposure levels (L_{EX}) are greater than 85 dBA for an eight hour day. The Code of Practice for Audiometry in these guidelines gives procedures to be followed. The Guidelines reference CSA Standards Z107.4 (8) and Z107.6 (draft) (9).

Warning Signs

Although warning signs are described in six of the present occupational noise laws in Canada, the requirements vary, particularly in the wording of the sign. The Federal Government, New Brunswick, Manitoba, Ontario and Quebec, require warning signs where the level is greater than 90 dBA, Saskatchewan, Nova Scotia and Alberta where the level is greater than 85 dBA. The Federal Government also requires signs where the impact noise is greater than 140 dB peak sound pressure level. British Columbia, requires signs where levels exceed the specified limits. Newfoundland, Prince Edward Island, and Yukon do not require warning signs.

The Canada Labour Code and British Columbia require signs warning persons that a noise hazard exists and the type of hearing protection required. Canada Labour Code also requires the permissible exposure time to be stated. Saskatchewan requires the range of noise levels measured to be stated. New Brunswick requires signs which 1) warn individuals that hearing protectors are required, 2) are in contrasting letters at least 4" (102 mm) high and 3) are at least 18" x 24" (457 mm x 609 mm) in size.

Manitoba legislation requires warning signs that not only clearly identify that a potential sound exposure hazard exists but also that hearing protection is required to be worn and used in that area. The Federal/Provincial Guidelines (4) require that, where hearing protectors must be worn, warning signs be posted at the work place to specify this.

Noise Surveys

Surveys of noisy places are specifically required to be conducted by the employer by the Federal Government, Manitoba, Saskatchewan, and Quebec. Ontario's proposed legislation contains a similar requirement. The Federal Government states that noise surveys may be required where the safety officer believes levels are sufficient to impair employees hearing. Saskatchewan legislation states that all occupational establishments with noise levels ≥ 85 dBA must be surveyed and documented within 3 months of the promulgation of the regulation and thereafter when there is reason to believe that substantial changes in noise levels have occurred. Quebec Legislation (36a) states that any employer hiring more than 50 workers should make yearly noise surveys in areas where the noise levels may be above the allowable limit and also within 30 days of a new installation being installed. Ontario proposed regulations contain a detailed code for noise measurement as do the Federal/Provincial Guidelines (4). In most provinces, a noise survey comes under the powers of an inspector.

Noise and Vibration Control

A number of regulations specify the need for "engineering controls" (see Table 3.4). Quebec specifically mentions noise and vibration control. In their workplace regulations under the Quebec Environmental Quality Act (36), it is stated that noise and vibration capable of producing harmful effects on workers shall be reduced by one or all of the following means:

(a) isolation of noise sources;
(b) limitation of the intensity and duration of these noises; and
(c) installation of a soundproof device to isolate working areas from sources of noises or vibrations.

4.0 HEARING CONSERVATION PROGRAMMES AND EDUCATION

Whenever noise exposures are such that an unavoidable risk of permanent hearing loss exists, according to WHO, a hearing conservation programme should be provided (46,4). In the author's opinion, such programmes should contain 3 elements: education concerning the hazards of noise; education in the proper use and supervision of the wearing of hearing protection; and monitoring audiometry, including periodical medical examination, performed when necessary. Monitoring audiometry, if properly planned and executed, identifies workers at risk from incipient hearing impairment, so that they can be removed from the noisy workplace before excessive irreversible damage is caused. (Monitoring audiometry has recently become a controversial issue and is not supported by the Canadian Centre for Occupational Safety and Health). Since occupational noise regulations allow a certain risk of permanent hearing loss, a hearing conservation programme is highly desirable in addition to the specification of maximum exposure levels. Hearing conservation programmes are considered desirable when 8 hour daily exposures exceed 75 dBA (46). Present concepts of acceptable risk and economic constraints limit the practical application of these programmes in most countries including Canada to levels around 85 dBA.

There is good evidence that well managed hearing conservation programs do protect the hearing of workmen (47a, 47b, 47c). Some aggressive hearing conservation programmes have been introduced into Canadian industry over the last 10 years and these should soon begin to bear fruit. More and more industries are becoming conscious of sound levels. Specifications for noise levels are being included when new machinery is ordered, and industries are becoming aware that very often the cost of engineering controls for minimizing noise is less than the cost of compensation paid for hearing loss. Awareness of the harmful effect of noise, both by labour and by management is probably the largest single factor that provides the incentive required to reduce occupational hearing loss.

Occupational noise regulations are beginning to recognize the importance of hearing conservation programs. Alberta regulations detail regular audiometric testing for noise exposed workers and a reporting system for those showing signs of hearing loss. British Columbia requires annual hearing tests for noise-exposed workers and records to be kept for the period of employment (48).

The Ontario proposed regulation contains a "Code for Medical Surveillance of Noise Exposed Workers". The objective of the Ontario Medical Surveillance programme is to protect the health of workers by: 1) evaluating the effect of noise on workers, 2) enabling remedial action to be taken when necessary; and 3) providing health education. To achieve this the programme must consist of the following: 1) pre-placement and periodic audiometric tests, 2) medical examinations as necessary, 3) health education, and 4) record keeping. The Manitoba regulation is discussed here as an example of a basic element of a hearing conservation programme. Other elements of the Manitoba programme include development of educational materials for employers and workers, and a Code of Practice, which contains detailed information to provide practical guidance with respect to provisions of the regulation. Exposure monitoring data, audiometric test results, health histories and associated reports must be maintained for the duration of a worker's exposure plus 10 years. The employer and workplace safety and health committee or worker representative are advised regarding the effectiveness of existing practices to control worker exposure to noise and the need for additional control measures.

The Federal/Provincial Guidelines (4) require a hearing conservation programme to be administered by the employer, where equivalent sound exposure levels (L_{EX}) are 85 dBA or greater in one work day. The hearing conservation programme is defined as a work place programme including provisions for: 1) noise measurement and assessment of workers' noise exposure, 2) engineering controls, work practices, hearing protectors, and warning signs, 3) maintenance of noise measurement and exposure records, 4) audiometric tests, 5) maintenance of workers confidential audiometric records, and 6) educational programs. All these provisions are required where exposure levels are $L_{EX} \geq 85$ dBA over a work day but 2) is only mandatory at $L_{EX} \geq 90$ dBA.

5.0 LIMITATIONS OF PRESENT REGULATIONS

Until recently, there has been a lack of uniformity of occupational noise regulations in Canada, and a lack of a firm scientific basis underlying the regulations. The publication of the Shaw report (2) draws on the 2 decades of such research to make general conclusions that help put present occupational noise regulations on a firm scientific base, and the Federal/Provincial Guidelines (4) provide the framework for more uniform occupational noise regulations in Canada.

The purpose of controlling occupational noise exposure is primarily to conserve hearing. One problem with this is that there are limits to the protection that can be afforded, and current regulations do allow some workers to lose some hearing. Another problem in the area of compensable hearing loss is the lack of agreement on the appropriate methods of assessing both hearing loss and hearing disability and their relationship with each other. The question of what constitutes a hearing handicap and how it should be measured has not been resolved. A successful method of assessing hearing handicap should take into account the economic and social handicap of the hard-of-hearing person and yet should be relatively quickly measured in a reproducible manner. At the present time evaluations of social and economic handicap are very time-consuming to undertake and are still in the experimental state (49,50). Current methods rely on the indirect relationship between hearing threshold as measured by pure tone threshold acuity and subjective complaints.

A limitation of any regulation is that its effectiveness relies heavily on its enforcement, voluntary or otherwise. Since most Canadian occupational noise regulations allow hearing protection to be used where the noise cannot be reduced to acceptable levels, the employer must not only provide hearing protection, but also ensure that it is worn properly to give adequate protection against hearing loss.

6.0 WORKER'S COMPENSATION FOR OCCUPATIONAL NOISE IN CANADA

In general industrial noise-induced hearing loss claims are accepted by the Workers' Compensation Boards if:

(a) there is an adequate history of exposure to hazardous noise in the workplace, and
(b) an otologist finds that the worker has a hearing loss that could have been caused by noise exposure.

It then has to be determined if the hearing loss is of sufficient magnitude to be considered pensionable.

Compensation for hearing loss due to occupational noise is dealt with very similarly in all provinces except British Columbia and Quebec, as shown in Table 6.1. This figure shows that most provinces use a 35 dB low fence (the smallest amount of hearing loss that is compensated) and an 80 dB high fence (total deafness in one ear). The hearing loss is calculated from an average of the hearing loss of 500, 1000, 2000 and 3000 Hz frequencies for each ear. In Quebec the 4000 Hz frequency is used in place of 3000 Hz. In British Columbia the better ear is weighted by 5/1 which means that the disability rating for the better ear is five times as great as the rating for the poorer ear. The disability rating schedule used by British Columbia is shown in Table 6.2, Table A. Total deafness in one ear is rated at the equivalent of 5% total body impairment. Total deafness in both ears is rated at 30% total body impairment.

Slight differences in the way some of the provinces compensate hearing loss include: 1) applying a presbycusis correction factor of .5 dB for each year over 60 (Newfoundland, Ontario and Alberta), 2) giving an additional 2% compensation for tinnitus (Ontario and Alberta), and 3) giving 60% disability for sudden complete bilateral deafness (New Brunswick and Alberta), who also have a schedule for unilateral deafness (see Table 6.2, Table B).

Hearing loss compensation in the British Columbia regulation presently varies significantly from the above. It is not subject to WCB Industrial Health and Safety Regulations, but follows an Act of the B.C. Legislature. However, they apparently have proposed legislation to change the audiometric frequencies averaged to include 3000 Hz. Since this recommendation has been under consideration for several years now and immediate action is not anticipated (45), the low fence would also increase from 28 dB to 35 dB (45). Their present disability rating schedule is shown in Table 6.2, Table C. British Columbia awards a lower percentage compensation for total deafness, 3% for one ear and 15% for both ears, however their definition of total deafness in one ear is 68 dB rather than 80 dB, and thus the actual monetary compensation is claimed to be comparable with other provinces (48).

Only the province of Ontario includes guidelines to be taken for rehabilitation in its draft. These include authorization for hearing aids, lip-reading classes and vocational rehabilitation (the latter when employees are recommended for non-hazardous noise exposure employment).

TABLE 6.1

WORKERS COMPENSATION FOR OCCUPATIONAL HEARING LOSS IN CANADA

PROVINCES	AUDIOMETRIC FREQUENCIES USED (Hz)	METHOD OF CALCULATION	LOW FENCE (ANSI/ISO)	HIGH FENCE (ANSI/ISO)	BETTER EAR CORRECTION	PRESBYCUSIS CORRECTION	% PER DECIBEL LOSS		MAXIMUM % FOR TOTAL DEAFNESS			
							Partial (Both Ears)	Unilateral or Acute Traumatic Hearing Loss	One Ear	Both Ears	Sudden Complete Bilateral Deafness	% FOR TINNITUS
Alberta	500, 1000, 2000, 3000	average	35 dB	80 dB	5/1	.5 dB each year over 60	A*	B*	5	30	60	2
British Columbia	500, 1000, 2000	average	28 dB	68 dB	4/1	-	C*	-	3	15	30	-
Manitoba Ontario Prince Edward Island	500, 1000, 2000, 3000	average	35 dB	80 dB	5/1	.5 dB each year over 60	A*	-	5	30	-	2
New Brunswick	500, 1000, 2000, 3000	average (rounded up to next 5 dB increment)	35 dB	80 dB	5/1	-	A*	B*	5	30	60	-
Newfoundland	500, 1000, 2000, 3000	average	35 dB	80 dB	5/1	.5 dB each year over 60	A*	-	5	30	-	-
North West Territories	500, 1000, 2000, 3000	average	30 dB	80 dB	5/1	.5 dB each year over 60	A* extended down to .1% at 30 dB	-	5	30	60	-

TABLE 6.1

WORKERS COMPENSATION FOR OCCUPATIONAL HEARING LOSS IN CANADA (continued)

PROVINCES	AUDIOMETRIC FREQUENCIES USED (Hz)	METHOD OF CALCULATION	LOW FENCE[1] (ANSI/ISO)	HIGH FENCE[1] (ANSI/ISO)	BETTER EAR CORRECTION	PRESBYCUSIS CORRECTION	% PER DECIBEL LOSS		MAXIMUM % FOR TOTAL DEAFNESS			% FOR TINNITUS
							Partial (Both Ears)	Unilateral or Acute Traumatic Hearing Loss	One Ear	Both Ears	Sudden Complete Bilateral Deafness	
Nova Scotia	500, 1000, 2000, 3000	average	35 dB	80 dB	5/1	.5 dB each year over 60	A*	-	5	30	60	Up to 5
Quebec	500, 1000, 2000, 4000	average	25 dB	65 dB	5/1	.5 dB each year over 60	Not known	-	5	30	30-60	-
Saskatchewan	500, 1000, 2000, 3000	average	35 dB	80 dB	5/1	-	A*	-	5	30	-	-

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* A, B, C, see Figure 4.2 Tables A, B, and C.

[1] fence means

TABLE 6.2 PERCENT DISABILITY FOR VARYING DEGREES OF HEARING LOSS

Table A. Partial Hearing Loss Where Both Ears are Affected

dB Hearing Loss	% Disability
35 dB (ANSI/ISO)	.4
40	.7
45	1.0
50	1.4
55	1.8
60	2.3
65	2.8
70	3.4
75	4.0
80	5.0

Table B. Unilateral Deafness (Alberta) or Acute Traumatic Hearing Loss (New Brunswick)

dB Hearing Loss	% Disability
30 dB (ANSI/ISO)	1
40	2
50	3
60	4
70	5

Table C. Non-Traumatic Hearing Loss (British Columbia)

Loss of Hearing in dB	% of Total Disability	
	Ear Most Affected	PLUS Ear Least Affected
0 - 27 (ANSI/ISO)	0	0
28 - 32	0.3	1.2
33 - 37	0.5	2.0
38 - 42	0.7	2.8
43 - 47	1.0	4.0
48 - 52	1.3	5.2
53 - 57	1.7	6.8
58 - 62	2.1	8.4
63 - 67	2.6	10.4
68 or more	3.0	12.0

Discrepancies exist in the relationship between percentage hearing loss and total pensional disability. In Canada total hearing loss is rated at between 15% and 50% of total pensionable disability. Blindness is equated with 100% pensionable disability. However, total hearing is one of the primary senses, and most jobs are impossible for the totally deaf and many are impossible for the hard of hearing (47).

Hearing loss produced by occupational exposure to noise has aroused increasing interest over the last decade (47). One of the main reasons for this is the rise in the number of claims. Table 6.3, shows, as an example, the dramatic increases in Ontario over the last 37 years. Recent figures illustrating the increase in costs is given in Table 6.3b. It is likely, as the cost increases, and engineering technology improves, that high noise levels will be eliminated by engineering controls of the source or by masking. Until such time the cost of compensation is borne directly by industry and thus passed back to the consumer. A similar, but less dramatic example of increases in costs is given for Manitoba in Table 6.4.

TABLE 6.3a PROVINCE OF ONTARIO: WCBO INDUSTRIAL HEARING LOSS CLAIMS (57)

YEAR	RECEIVED	PENSIONED
1950-55	10	2
1956	14	4
1957	17	4
1958	11	20
1959	50	9
1960	28	10
1961	28	10
1962	28	11
1963	36	14
1964	59	15
1965	92	12
1966	97	30
1967	100	46
1968	112	41
1969	177	58
1970	301	63
1971	370	130
1972	382	148
1973	582	208
1974	986	482
1975	1519	639
1976	2463	1066
1977	2405	1364
1978	2091	1338
1979	1992	1045
1980	2414	950
1981	2900	968
1982	3178	1458
1983	3119	1475
1984	3262	1249
1985	3080	1393
1986	3521	1372
1987	3866	1693

Table 6.3b PROVINCE OF ONTARIO: WCBO INDUSTRIAL HEARING LOSS CLAIMS (57)

Year	Number of Hearing Claims Initially Settled As Temporary Permanent Disabilities	Average Cost Per Claim
1983	631	$ 8,011
1984	847	9,321
1985	763	9,246
1986	914	9,814
1987	1,004	11,199

TABLE 6.4

PROVINCE OF MANITOBA : WCBM INDUSTRIAL HEARING LOSS CLAIMS (52)

Year	Total No. Claims Filed	Total Awarded Permanent Disability	Av. Disability Rating %	Approx. Av. Capitalized Award $	Total Approx. Cost to Industry
1974	37	19	6.1	4.7K	92K
1975	61	30	6.7	5.0K	152K
1976	96	57	6.7	6.3K	359K
1977	96	44	6.3	6.9K	306K
1978	86	44	6.3	7.0K	309K
1979	116	52	6.1	7.7K	399K
1980	146	45	7.3	8.2K	368K
1981	231	73	5.8	8.2K	594K
1982	240	80	6.4	9.6K	772K
1983	321	89	5.7	9.1K	806K
1984	317	86	5.8	10.5K	899K
1985	214	58	6.4	12.9K	750K

7.0 NATIONAL HEALTH & WELFARE PROGRAMME IN PROTECTION FROM OCCUPATIONAL HEARING LOSS

National Health and Welfare (NHW) has had a number of activities in the area of occupational hearing loss over the years. The Medical Services Branch has an ongoing responsibility for monitoring the hearing and work environment of public service employees and for enforcing Treasury Board Standards for occupational noise exposure and hearing conservation. The Health Services and Promotion Branch publishes topical documents related to occupational noise from time to time, the most recent document concerns acquired hearing impairment in adults (53).

The Health Protection Branch has a responsibility for protecting the health of Canadians from the adverse effects of noise. This has been carried out by the Non-Ionizing Radiation Section (NIRS) of the Radiation and Medical Devices Bureau, Health Protection Branch. The noise program began with a background document entitled "Noise Hazard and Control", published in 1979 (54). This document summarized known health effects of noise (both auditory and non-auditory) indicated the major sources of noise, and described Canadian noise legislation. It also indicated areas of incomplete knowledge, mainly related to noise-induced hearing loss, which were:

(a) the effects of impulse noise and continuous noise in the 4 - 6 kHz frequency range
(b) the accuracy and effectiveness of screening audiometric testing and screening audiometers
(c) the assessment of the total noise exposure of Canadians and its relation to hearing loss, and
(d) the investigation of the amount of hearing loss incurred from various noise exposure limits.

Since then, noise levels and the progression of noise-induced hearing loss in specific industries in Canada have been evaluated (55). The method of testing hearing (audiometric testing), and the acoustic accuracy of audiometers have also been investigated (56).

The most recent Canadian activity has been the preparation of the "Guidelines for Regulatory Control of Occupational Noise Exposure and Hearing Conservation. Part I. Model Regulation" (4), described in Section 2.3.

There is an ongoing active interest in Canadian and International Noise standards work to support activities in protection from the hazards of noise exposure.

8.0 CONCLUSIONS AND RECOMMENDATIONS

It is recommended that the Federal/Provincial Guidelines (4) be used as a basis for future occupational noise regulations in Canada in conjunction with the scientific basis provided by the Shaw Report (2). In summary, therefore, occupational noise exposure and hearing loss regulations are particularly encouraged to include the following:-

(1) Provision for education of employers and employees.
(2) All possible aspects of hearing conservation programmes.
(3) Equivalent continuous noise levels (or noise exposure levels) be used to measure sound exposure (L_{Aeq} or L_{Aex}).
(4) 3 dB dose trading relationship.
(5) 90 dBA sound exposure limit for an 8 hour working day.
(6) No distinction be made between impulsive or other type of noise.

It is also recommended that new installations be required before construction to obtain approval so that occupational noise criteria will be met.

Finally, the increasing number of claims for occupational hearing loss and the cost of its compensation should provide a strong incentive for effective hearing conservation programmes.

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SYNTHESE SUR LES PRINCIPALES TECHNIQUES DE MESURE DE REPONSE IMPULSIONNELLE EN ACOUSTIQUE DES SALLES

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RESUME

Cet article fait le point sur les principales techniques de mesure d'une réponse impulsionnelle en acoustique des salles. Elle comprend deux parties : la première est consacrée aux techniques dites traditionnelles, tandis que la seconde traite des méthodes modernes.

Cette étude comporte, pour chaque technique proposée :

- une approche théorique,
- ainsi que la mise en oeuvre pratique métrologique.

Une présentation systématique des principaux avantages et inconvénients relatifs à l'utilisation de chaque technique constitue aussi le souci majeur de cette synthèse.

Sur le plan du traitement du signal, ce travail met en évidence, dans sa seconde partie, le fait que toutes les techniques récentes de mesure ont un fondement théorique commun basé sur le doublet temporel "convolution et corrélation".

ABSTRACT

We examine the principal methods for measuring impulse reponses in room acoustics. The first part of the paper is a synthesis of conventional techniques ; the second discusses modern methods, together with the main advantages and disadvantages of the techniques. It is shown in the second part that all new techniques in our signal processing are based on convolution and correlation theory.

INTRODUCTION

La difficulté majeure rencontrée dans le domaine des techniques de mesures en acoustique des salles est due au fait que l'on ne connaît pas la description mathématique (modèle) qui caractérise le comportement de ces systèmes. La démarche habituellement utilisée par les acousticiens est alors d'expérimenter directement sur le système en vue de déterminer ses propriétés acoustiques. Cette expérimentation conduit en général à la mesure de la réponse impulsionnelle, opérateur temporel propre du système. La détermination de cette fonctionnelle se fait par l'étude de la réponse du système à des signaux particuliers d'excitation. On verra, dans cette étude, que les techniques de mesure se différencient surtout par la nature même du signal test.

Cet article discute aussi des principaux avantages et inconvénients relatifs à l'utilisation de chaque technique. Quant aux approches mathématiques formulées dans ce travail, elles font référence à l'hypothèse opérationnelle d'acoustique linéaire dans le cas monovariable stationnaire et ergodique.

I. TECHNIQUES TRADITIONNELLES

I.1. Formalisme mathématique

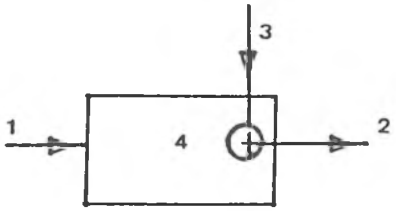

Fig. 1.1 - Représentation d'un canal acoustique (salle) :

1 - signal d'excitation
2 - signal de sortie
3 - bruit additif n(t)
4 - canal acoustique h(t)

L'ensemble de ces techniques de mesures traditionnelles ou conventionnelles est fondé sur la théorie d'analyse spectrale.

La réponse impulsionnelle h(t) d'un canal acoustique (salle) de la fig. 1.1 est donnée par l'expression intégrale :

$$h(t) = \int_{D(\nu)} H(\nu)\, e^{2j\pi\nu t} d\nu \; ; \qquad (1)$$

$h(t)$ est une fonction physique et $D(\nu)$ est l'étendue spectrale de $H(\nu)$.
Soit symboliquement $h(t) \rightleftharpoons H(\nu)$

Le couple (h, H) constitue une "paire" de Fourier. La formule intégrale (1) met en relation les deux formes de représentations temporelle et fréquentielle de la caractéristique fonctionnelle d'une salle au moyen de l'opération de transformation de Fourier, considérée comme outil mathématique fondamental de la métrologie fréquentielle.

Certains analyseurs bicanaux -et c'est le cas du HP 5420- permettent de mesurer directement la réponse impulsionnelle à partir d'une mesure de densité spectrale d'interaction (DSI) appelée communément "interspectre" et notée "$S_{ij}(\nu)$" dans ce texte, avec $i, j = 1,2,3,\ldots$. Si $i = j$ on a le cas de l'autospectre.

Si $X(\nu)$ et $Y(\nu)$ sont respectivement les représentations fréquentielles des signaux d'entrée $x(t)$ et de sortie $y(t)$ du système à mesurer (salle) : on a la relation spectrale suivante :

$$Y(\nu) = H(\nu) \cdot X(\nu) \tag{2}$$

ou $X^*(\nu) \cdot Y(\nu) = H(\nu)\, X^*(\nu)\, X(\nu)$; $X^*(\nu)$ est le complexe conjugué de $X(\nu)$

soit $S_{12}(\nu) = H(\nu)\ S_{11}(\nu)$

Comme dans la pratique, on considère :

$$G(\nu) = \begin{cases} 2\,S(\nu) & \text{pour} \quad \nu > 0 \\ S(\nu) & \text{pour} \quad \nu = 0 \\ 0 & \text{pour} \quad \nu < 0\ ; \end{cases}$$

on peut écrire aussi que $G_{12}(\nu) = H(\nu) \cdot G_{11}(\nu)$,

d'où l'on tire $$H(\nu) = \frac{G_{12}(\nu)}{G_{11}(\nu)} \tag{3}$$

Pour tenir compte de l'effet du bruit additif $n(t)$ sur le signal de sortie $y(t)$, il faut corriger la relation (3) comme suit :

$$G'_{12}(\nu) = X^*(\nu)\ \left[\, Y(\nu) + N(\nu) \,\right]$$

où $N(\nu)$ est la représentation fréquentielle du bruit $n(t)$

On a finalement :

$$H'(\nu) = \frac{G'_{12}(\nu)}{G_{11}(\nu)} = H(\nu) + \frac{G_{13}(\nu)}{G_{11}(\nu)} \tag{4}$$

La contribution du bruit est ici représentée par le terme $G_{13}(\nu)/G_{11}(\nu)$, terme rendu généralement très petit en augmentant le nombre de réalisations mis en jeu dans l'opération de moyennage.

I.2. Sources d'excitations conventionnelles

En métrologie conventionnelle acoustique, il y a principalement deux grandes familles des signaux tests d'excitation : les signaux aléatoires à corrélation microscopique et les excitations impulsives.

Pour ce qui est des signaux aléatoires à corrélation microscopique, le processus représentatif de cette catégorie des signaux est le "bruit blanc", b(t). Sur le plan de la terminologie, il convient de faire remarquer que l'appellation "bruit blanc" est liée à la représentation fréquentielle, tandis que le concept de corrélation microscopique correspond à la représentation temporelle.

Ainsi, un signal aléatoire est dit à corrélation microscopique si sa fonction d'autocorrélation est assimilable à une distribution de Dirac :

$$s_{bb}(\tau) = 1/2\ No\,\delta\,(\tau) \qquad (5)$$

Cela se traduit en fréquence par la constance spectrale :

$$S_{bb}(\nu) = 1/2\ No \text{ (densité spectrale de puissance constante).}$$

Quant aux excitations impulsives, dites souvent aussi "impacts" -et c'est le cas, par exemple, du "coup de pistolet"-, elles sont également d'usage courant en analyse acoustique. Mais le problème qui se pose est que le modèle du dispositif n'est pas normalisé, en même temps que le modèle mathématique du signal généré diffère d'un laboratoire à un autre. Ainsi, par exemple, dans certaines études menées au LAMI [1], on a réutilisé la formulation du signal impulsif modélisé [2] par la fonction :

$$p(t) = \begin{cases} po.\ e^{-at}\ (1 - at) & \text{pour } t \geq o \\ o \text{ pour } t < o \end{cases}$$

avec $a = 1/to$; to étant la largeur de l'impulsion.

I.3. Aspects méthodologiques pratiques

I.3.1. Cas d'une analyse avec une source impulsive (impact)

C'est l'approche la plus directe dans la pratique de mesure de la réponse impulsionnelle d'une salle. Elle consiste à exciter celle-ci avec un tel signal impulsif, et d'observer directement la réponse (Fig. 1.2).

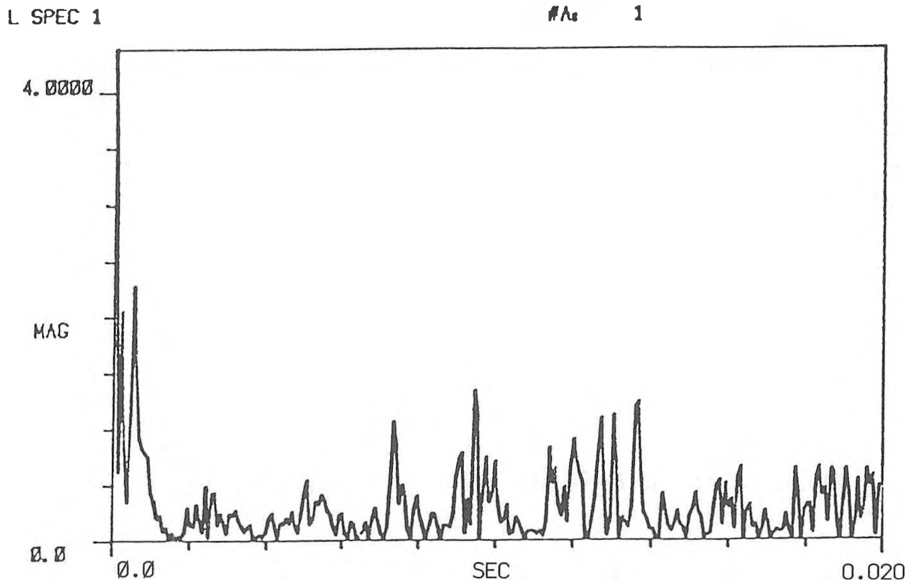

Fig. 1.2 - Réponse impulsionnelle d'une salle excitée par un coup de pistolet

A cette simplicité de mise en oeuvre de la mesure, viennent s'ajouter deux inconvénients :

1. Irrégularité de la distribution énergétique à toutes les fréquences utiles.
2. Médiocrité de la dynamique et de la reproductivité des résultats.

1.3.2. Analyse avec une source de bruit blanc

Dans la pratique, la reltion (4) s'interprète en se basant sur la paire de Fourier (h, H), ce qui permet d'écrire :

$$h'(t) = \int_{D(\nu)} H'(\nu) e^{2j\pi\nu t} d = \int_{D(\nu)} \left[H(\nu) + \frac{G_{13}(\nu)}{G_{11}(\nu)} \right] e^{2j\pi\nu t} d\nu$$

$$= \int_{D(\nu)} \frac{G_{12}(\nu)}{G_{11}(\nu)} e^{2j\pi\nu t} d\nu + \int_{D(\nu)} \frac{G_{13}(\nu)}{G_{11}(\nu)} e^{2j\pi\nu t} d\nu \qquad (6)$$

Comme le signal d'entrée $x(t)$ est dans ce cas un processus à corrélation microscopique, donc à densité spectrale de puissance (DSP) constante, c'est-à-dire, ici, $G_{11}(\nu) = 1/2\ N_0$, la relation (6) devient :

$$h'(t) = \frac{2}{N_o} \int_{D(\nu)} G_{12}(\nu)\, e^{2j\pi\nu t} d\nu + \frac{2}{N_o} \int_{D(\nu)} G_{13}(\nu)\, e^{j\pi t\nu} d\nu \qquad (7)$$

D'autre part, en considérant les intercorrélations et les interspectres : les couples (g_{12}, G_{12}) et (g_{13}, G_{13}) constituent deux paires de Fourier.

D'où finalement :

$$h'(t) = \frac{2}{N_o} \left[g_{12}(t) + g_{13}(t) \right] \qquad (8)$$

Les relations (7) et (8) mettent en évidence deux façons d'opérer la mesure d'une réponse impulsionnelle.

Premièrement, par la mesure de l'interspectre, c'est-à-dire de la densité interspectrale d'énergie (DIE) sur laquelle on applique une transformation de Fourier. Ce procédé est le plus ancien et le plus répandu sur les analyseurs spectraux de traitement du signal.

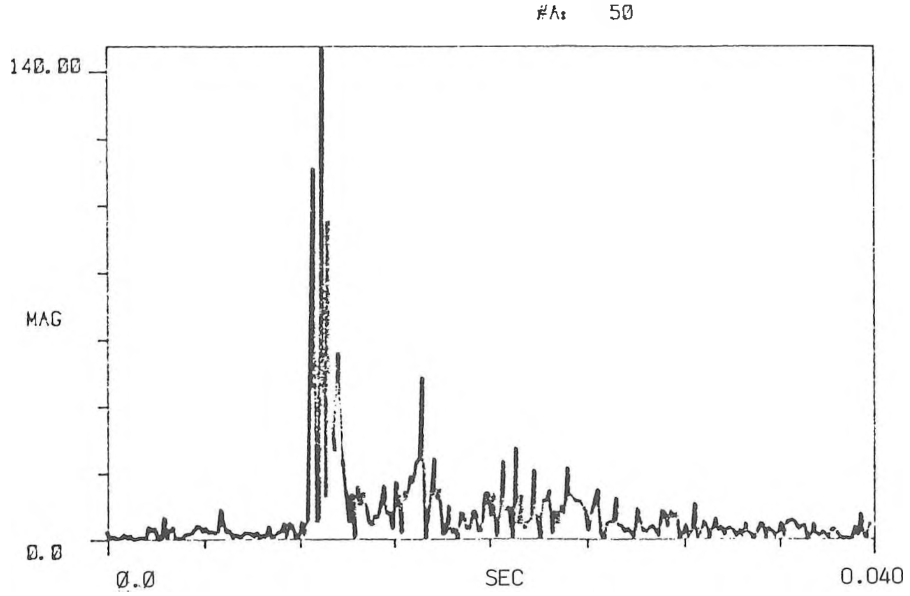

Fig. 1.3 - Réponse impulsionnelle de la salle, obtenue par la méthode spectrale.

Deuxièmement : par la mesure de la fonction d'intercorrélation.

Avec l'emploi des sources à corrélation microscopique, il y a deux avantages essentiels : dynamique adéquate et possibilité d'assurer l'uniformité de la distribution temporelle énergétique (utilisation de haut parleur à rayonnement omnidirectionnel).

Par contre, le principal obstacle de cette approche est qu'il faut faire un nombre assez grand de moyennages (50 par expérience) avant toute validation d'un résultat de mesure (Fig. 1.3).

II. TECHNIQUES MODERNES

II.1. Conceptualisation mathématique

Les différentes approches métrologiques modernes de mesure d'une réponse impulsionnelle sont actuellement essentiellement basées sur deux opérateurs de traitement du signal, à savoir : la convolution et la corrélation.

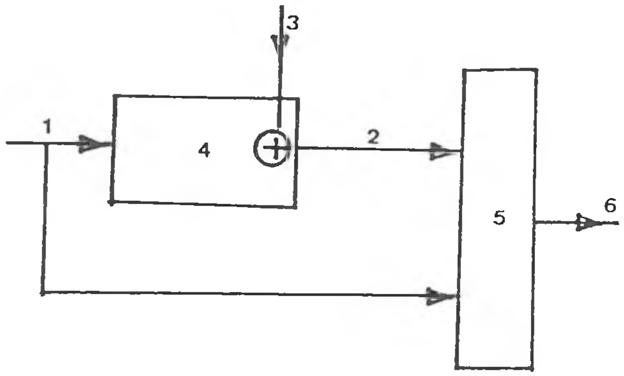

Fig. 2.1 - Synoptique de mesure d'une réponse imulsionnelle par la méthode de corrélation :

1 - signal d'excitation
2 - réponse de la salle
3 - bruit additif
4 - canal (salle)
5 - corrélateur
6 - réponse impulsionnelle

Si, dans un premier temps, on suppose que le bruit $n(t)$ n'agit pas sur la salle (Fig. 2.1), la réponse de la salle est donnée par la formule de VASCHY [3] , comme suit :

$$y'(t) = (h*x)(t) \; ; \; * \text{ est le produit de convolution} \qquad (9)$$

En admettant l'influence du bruit $n(t)$ dans la salle, on déduit aussi sa participation en sortie :

$$y''(t) = (h*n)(t) \qquad (10)$$

En tenant compte de l'hypothèse de linéarité émise en introduction, on obtient la réponse globale de la salle par additivité :

$$\begin{aligned} y(t) &= y'(t) + y''(t) \\ &= (h*x)(t) + (h*n)(t) \end{aligned}$$

D'où l'intégrale de convolution :

$$y(t) = \int_0^\infty [x(t-\Theta) + n(t-\Theta)]\ h(\Theta)d\Theta \ ; \qquad (11)$$

D'autre part, en considérant la statistique du second ordre des signaux x(t) et y(t) en corrélation, on peut aussi écrire que :

$$s_{21}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_0^T y(t)x(t-\tau)\ dt \ ; \text{ fonction d'intercorrélation} \qquad (12)$$

$$s_{11}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_0^T x(t)x(t-\tau)\ dt \ ; \text{ fonction d'autocorrélation} \qquad (13)$$

En introduisant dans (12) l'expression de y(t) donnée par l'intégrale de convolution, on obtient le développement suivant :

$$s_{21}(\tau) = \int_0^\infty \lim_{T\to\infty} \frac{1}{T} \int_0^T [\ x(t-\Theta) + n(t-\Theta)]\ x(t-\tau)\ h(\Theta)dtd\Theta$$

En admettant l'hypothèse de la décorrélation statistique entre les signaux x(t) et n(t), on a :

$$s_{13}(\tau-\Theta) = \lim_{T\to\infty} \frac{1}{T} \int_0^T n(t-\Theta)\ x(t-\tau)\ dt = o$$

D'où finalement :

$$s_{21}(\tau) = \int_0^\infty s_{11}(\tau-\Theta)\ h(\Theta)\ d\Theta \qquad (14)$$

On constate, en définitive, que le concept du doublet temporel "convolution et corrélation" est explicité par la relation qui lie la FAC (Fonction autocorrélation) du signal d'entrée et la FIC (Fonction d'intercorrélation) des signaux d'entrée et de sortie du système analysé.

Soit symboliquement :

$$s_{21} = s_{11} * h$$

Il convient donc de souligner que la relation (14) est une formulaiton générale intégrale pour la mesure d'une RI (réponse impulsionnelle).

II.2. Principes généraux opératoires

On peut grouper en trois catégories les différentes techniques récentes de mesure de réponse impulsionnelle en acoustique des salles : les techniques de déconvolution numérique, les méthodes de corrélation et les techniques de filtrage inverse.

II.2.1. Technique de déconvolution numérique

Le principe de cette approche peut être expliqué à partir de l'équation fondamentale de convolution (9). La déconvolutioin consiste à résoudre cette équation par rapport à $h(t)$, à partir des enregistrements sur un intervalle de temps fini T $(0 \leqq t \leqq T)$ des signaux d'entrée-sortie $x(t)$ et $y(t)$.

Le problème de la déconvolution étant analytiquement complexe, on s'oriente en général vers des hypothèses d'approximation comme, par exemple :

$$x(t) = x(n\Delta t), \text{ avec } N\Delta t = T \text{ et } n = 1,\ldots, N$$

pour $n\Delta t < t < \Delta t(n+1)$: Δt est le pas d'échantillonnage.

$$h(t) = h\left(\frac{2n+1}{2}\Delta t\right)$$

L'opération de convolution étant commutative, l'équation (9) s'écrit aussi :

$$y'(t) = \int_{o}^{t} h(t-\Theta) \,.\, x(\Theta)\, d\Theta$$

on approche alors $y'(t)$ par l'expression

$$y'(n\Delta t) = \Delta t \sum_{i=o}^{n-1} h\left(\frac{2n+1}{2}\Delta t - i\Delta t\right) . \, x(i\Delta t)$$

soit, en écriture matricielle :

$$Y' = \Delta t . X . H \tag{15}$$

avec $Y'^{T} = \left[y'(\Delta t) \;\; y'(2\Delta t) \;\ldots\; y'(N\Delta t) \right]$

$$H^T = [\ h\,(\frac{\Delta t}{2}) \quad h\,(\frac{3\Delta t}{2}) \quad \ldots \qquad h\,(\frac{2N-1}{2}\ \Delta t)$$

et
$$X = \begin{vmatrix} x(o) & 0 \quad \ldots & 0 \\ x(\Delta t) & x(o) & 0 \ldots 0 \\ x\,[\,(N-1)\Delta t] & x\,[\,(N-2)\,\Delta\ t] \ \ldots . & x(o) \end{vmatrix}$$

Si la valeur du signal d'entrée $X(0^+)$ est $\neq$ 0, alors le déterminant de la matrice X est $\neq$ 0, et donc à partir de (15) on obtient :

$$H = \frac{1}{\Delta\ t} \cdot X^{-1} \cdot Y'$$

L'inconvénient majeur de cette approche est qu'elle ne traite pas les bruits additifs inconnus $n(t)$ qui s'ajoutent sur la sortie $y'(t) = h(t) * x(t) + n(t)$: ceci contrairement à la méthode de corrélation qui même en présence de telles perturbations donne encore $s_{21} = s_{11} * h$ (cas où ces perturbations sont supposées indépendantes de l'excitation $x(t)$).

II.2.2. Typologie des signaux tests et approches opératoires pour la méthode de corrélation

La description des signaux tests faite sommairement ici est celle qui consiste à permettre de solutionner l'intégrale de convolution (14) en vue d'en tirer la réponse impulsionnelle.

Les sources à corrélation microscopique sont aussi d'usage courant en métrologie moderne acoustique.

Cela se justifie surtout par la nature impulsionnelle de leur FAC comme signalé au pararaphe I.2.

Dans ce cas, la relation (14) devient :

$$s_{21}(\tau) = \frac{1}{2}\, N_o \int_o^{\infty} \delta\,(\tau-\Theta)\ h(\Theta)\ d\Theta$$

soit
$$s_{21}(\tau) = \frac{1}{2}\, N_o\ h(\tau) \qquad (16)$$

Donc au coefficient $1/2\ N_o$ près, on remarque que la FIC est égale à la RI recherchée.

Il y a aussi les séquences binaires pseudo-aléatoires (SBPA) qui sont utilisées comme sources modernes d'excitation [4] , [5]. Une SBPA, appelée aussi communément "séquence à longueur maximale" ou encore "M-séquence", est une source réalisée à partir d'une configuration polynomiale primitive $P_n(x)$ de degré n (avec $N = 2^n - 1$

la longueur de la séquence) permettant de spécifier les rebouclages nécessaires d'un registre à décalage binaire [6] .

La FAC d'une telle séquence à longueur temporelle maximale $T_{max} = (2^n - 1)\,\Delta T$, est donnée par :

$$s_{SBPA}(\tau) = s_{11}(\tau) = \begin{cases} 1 \text{ pour } \tau = 0 \\ -\frac{1}{T} \text{ pour } 1 \leq \tau \leq (2^n - 1)\,\Delta T \end{cases}$$

avec $\Delta T = 1/F$ où F est la fréquence d'horloge de fonctionnement du registre.

Cette FAC présente une analogie formelle avec l'approche physique de la distribution de Dirac ; ce qui permet de la formaliser en représentation en distribution comme suit :

$$s_{11}(\tau) = (1 + \frac{1}{T})\,\delta(\tau) - \frac{1}{T} = \delta(\tau) - \frac{1}{T}$$

Dans ce cas, où l'excitation est une SBPA, l'égalité (14) devient alors :

$$s_{21}(\tau) = \int_0^{\infty} \delta(\tau-\Theta)\,h(\Theta)\,d\Theta - \frac{1}{T}\int_0^{\infty} h(\Theta)\,d\Theta$$

soit finalement :

$$s_{21}(\tau) = h(\tau) - h_{moy} \qquad (17)$$

où h_{moy} est la composante continue de la RI rendue généralement petite par un bon réglage du système de mesure.

II.2.2.1. Traitement numérique

Etant donnéque dans les deux cas envisagés précédemment (excitations à corrélation microscopique et SBPA), les solutions finales de l'intégrale de convolution (14) données par (16) et (17) mettent en évidence le caractère proportionnel entre la FIC et la réponse impulsionnelle : le traitement numérique à effectuer consiste globalement à évaluer l'estimateur temporel discret de corrélation $\hat{s}_{21}$ donné par :

$$\hat{s}_{21}(i) = \frac{1}{N}\sum_{k=o}^{N-1} y(k)\,x(k-i)$$

Pour une analyse avec une excitation à corrélation microscopique on procède d'abord, dans la pratique, à l'acquisition puis au stockage en fichiers des signaux d'entrée et de sortie échantillonnés $x(n)$ et $y(n)$.

THE COMPLETE ACO

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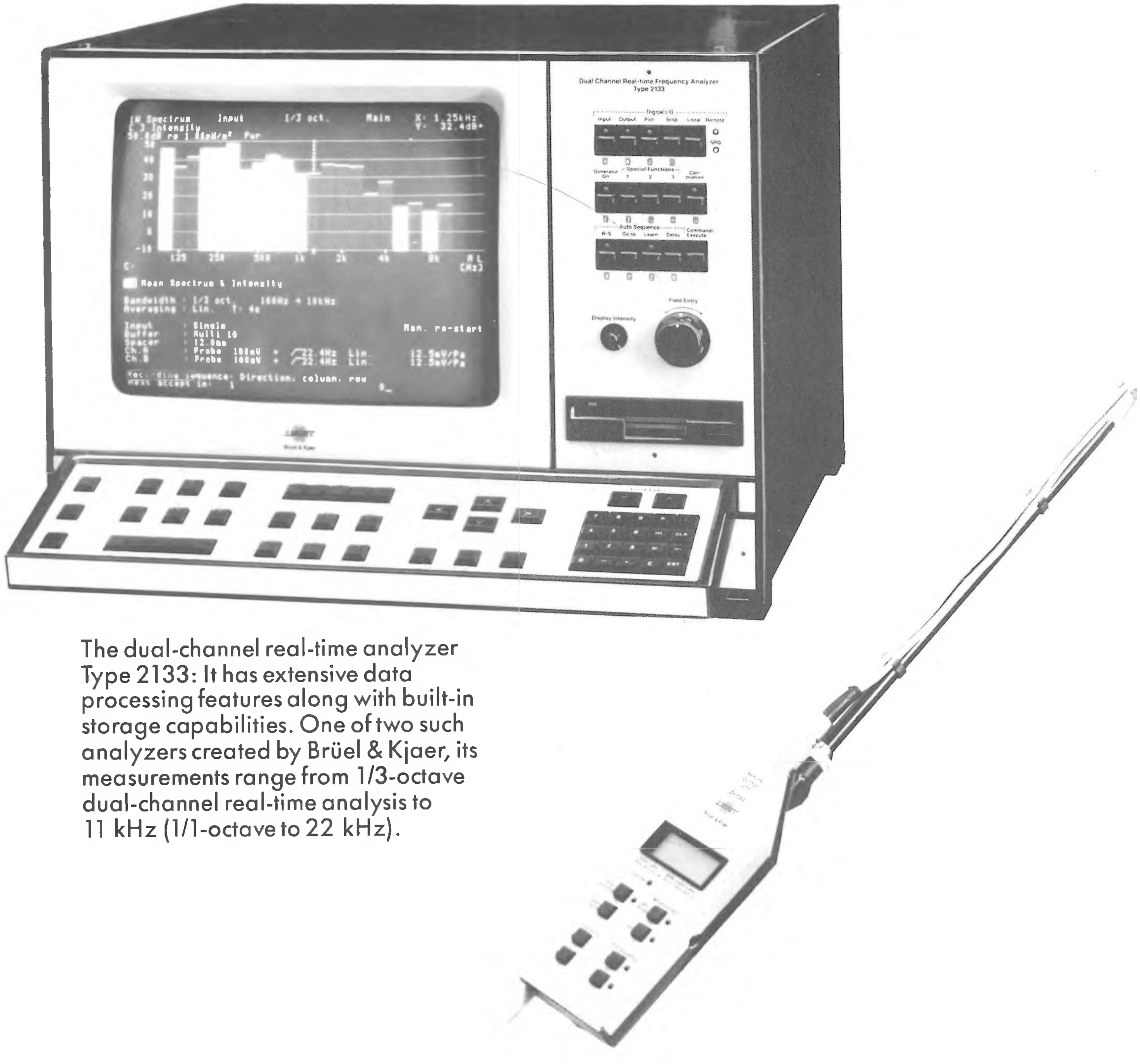

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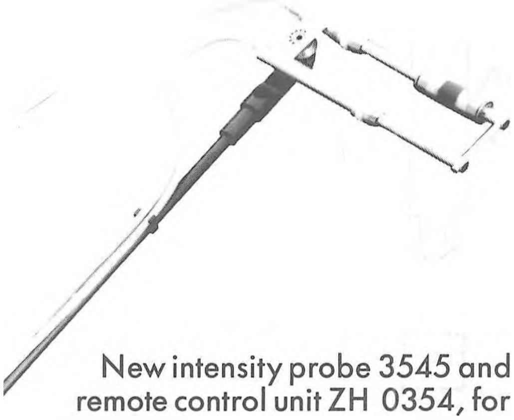
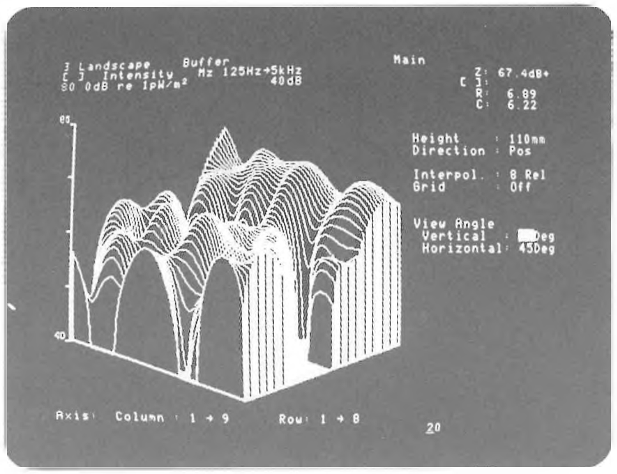


New intensity probe 3545 and remote control unit ZH 0354, for direct connection to, and control of, Analyzer 2133.



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] Landscape     Buffer                 Main
[ ]  Intensity   Mz 125Hz→5kHz              Z:  67.4dB+
80 0dB re 1pW/m²            40dB         [ ]:
                                            R:  6.89
                                            C:  6.22

                                    Height      : 110mm
                                    Direction   : Pos

                                    Interpol.   : 8 Rel
                                    Grid        : Off

                                    View Angle
                                     Vertical   :  Deg
                                     Horizontal : 45Deg

Axis:  Column : 1 → 9      Row: 1 → 8        20
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An MS-DOS compatible data storage is used in the built-in disc drive. An optional intensity mapping software package, the BZ 7021, is also available.

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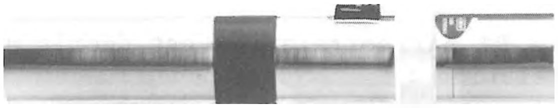

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Les opérations relatives à ce traitement, à savoir : le pilotage du CAN (convertisseur analogique/numérique), l'acquisition, le stockage, le calcul proprement dit de l'estimateur ainsi que le moyennage, sont réalisées à l'aide du calculateur HP 9000.

La fig. 2.2 montre le dispositif expérimental utilisé.

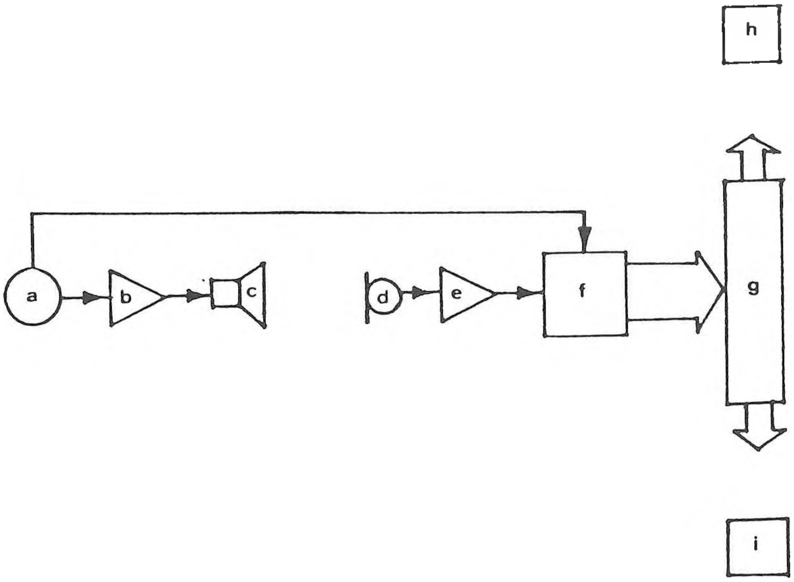

Fig. 2.2 - Dispositif expérimental :

a - source
b - amplificateur
c - haut-parleur
d - microphone
e - amplificateur de mesure
f - CAN
g - calculateur (HP 9000)
h - unité de disque
i - terminal graphique

L'inconvénient majeur rencontré dans cette approche métrologique est le temps relativement assez long que prend le calcul de l'estimateur.

Avec une SBPA, le calcul de la RI par corrélation est décrit en termes de multiplication matricielle par la relation :

$$\hat{s}_{21} = \frac{1}{N} X_N \cdot Y_N$$

où X_N est alors un signal représenté en matrice carrée (dimension = $2^n - 1$) constituée d'éléments obtenus par shiftage circulaire (droite) de la séquence symétrisée par assignation des valeurs ± 1 aux deux états binaires (1 en -1 et 0 en 1) et Y_N, un vecteur de longueur N.

Ce cas où la salle est excitée par un tel processus, revêt en pratique une importance particulière, car cela permet de minimiser les opérations nécessaires pour l'évaluation de l'estimateur de corrélation par l'utilisation de l'algorithme rapide de transformation d'Hadamard (THR).

On montre [5] avec cet algorithme, que le nombre d'opérations est sensiblement égal à $2{,}5\ N \log_2 N$ au lieu de N^2 classiquement. Ainsi, le gain en nombre d'opérations peut se chiffrer par :

$$G.O. = \frac{N^2}{2{,}5.N.\log_2 N} = \frac{N}{2{,}5\ \log_2 N}$$

Exemple : pour 512 points, l'algorithme rapide effectue 22 fois moins d'opérations que le calcul direct conventionnel, et, pour 4 094 points, il réalise 136 fois moins d'opérations.

Il convient aussi de mentionner que les SBPA sont des signaux d'excitation à faible niveau, ce qui rend plus acceptable l'hypothèse de linéarité acoustique. La seule difficulté qui se présente est celle de passer par une phase de calculs initiaux qui consiste à mettre la matrice X_N de la SBPA sous forme d'une matrice d'Hadamard, un préalable pour l'application de cet algorithme.

Il est utile de rappeler ici que la matrice d'Hadamard (H) est une matrice carrée de dimension 2^n, dont les éléments sont +1 ou -1, et dont les lignes (ou les colonnes) sont mutuellement orthogonales.

Contrainte métrologique : il faut présumer de la durée de la RI à mesurer et s'assurer que cette durée est inférieure à la longueur temporelle maximale de la séquence T_{max} [7].

Pour réaliser le traitement relatif à cette partie, nous nous sommes référés en particulier aux travaux cités en référence [5] et [8]. A. LEMPEL [8] met en évidence et démontre l'équivalence (par permutation) entre la matrice d'une séquence à longueur maximale et la matrice d'Hadamard du même ordre ; tandis que J. BORISH et J. ANGEL [5] décrivent pour un système acoustique excité avec une SBPA, toute la démarche de mise en oeuvre du calcul de la FIC basé sur l'utilisation de la transformation rapide d'Hadamard.

Ainsi donc, quatre modules-programmes ont été créés :

- module d'acquisition de la réponse y(n) de la salle ;
- module de génération de la séquence ;
- module de calcul des transforamtions permutationnelles ;
- module de calcul proprement dit de la THR.

En ce qui concerne le module de calcul des transformations permutationnelles (P_1 et P_2), notre approche n'est plus basée sur la représentation matricielle de la séquence comme proposé dans [5] et [8], mais sur sa représentation "séquentielle-série", ce qui permet de stocker seulement un vecteur de longueur $N = 2^n - 1$ au lieu d'un tableau dimensionné (N x N). Ce mono-dimensionnement de la matrice a été rendu possible grâce au caractère déterministe de la séquence binaire pseudo-aléatoire.

Les figures 2.3 et 2.4 montrent les RI obtenues avec une excitation SBPA pour deux salles distinctes.

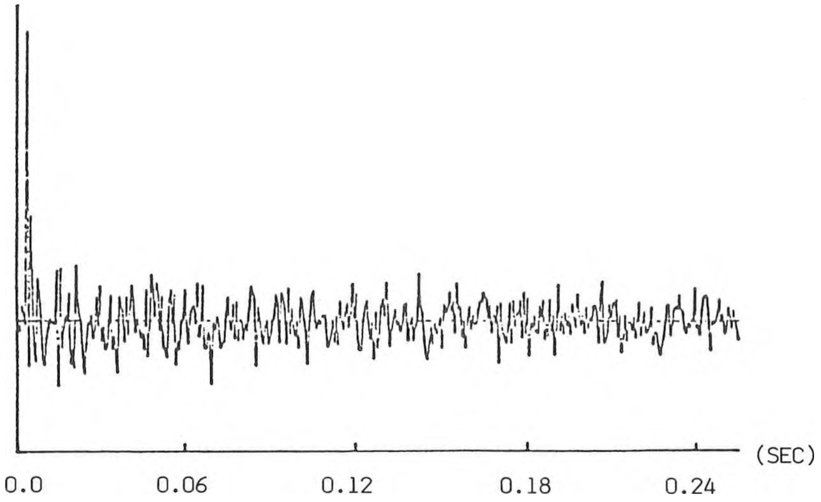

Fig. 2.3 - Réponse impulsionnelle d'une salle obtenue par corrélation classique avec une excitation binaire pseudo-aléatoire.

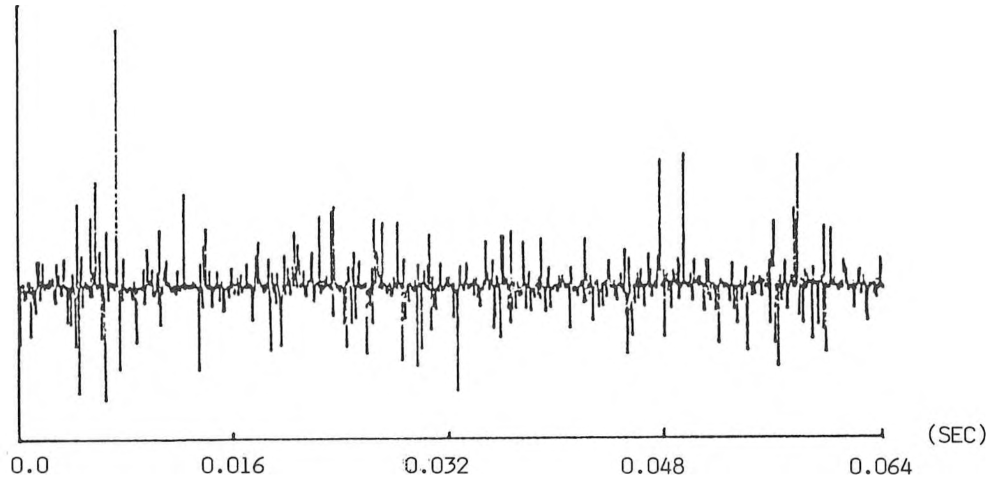

Fig. 2.4 - Réponse impulsionnelle d'une salle obtenue par corrélation utilisation la THR (on ne visualise que le début de cette réponse, les 1 024 premiers points).

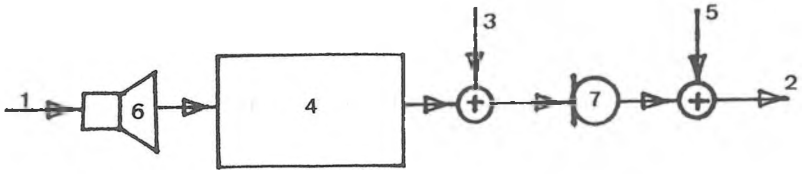

Fig. 2.5 - Système général de mesures acoustiques :

1 - signal d'excitation $x(t)$
2 - signal de sortie mesuré du système $y(t)$
3 - bruit acoustique $n_3(t)$
4 - canal acoustique $h_4(t)$
5 - bruit électrique $n_5(t)$
6 - haut-parleur $h_6(t)$
7 - microphone $h_7(t)$.

II.2.3. Techniques de filtrage inverse [9]

Sur la figure 2.5. la sortie $y(t)$ s'exprime en fonction des autres paramètres fonctionnels par :

$$y(t) = [x(t) * h_6(t) * h_4(t) + n_3(t)] * h_7(t) + n_5(t)$$

En posant : $n(t) = n_3(t) * h_7(t) + n_5(t)$:

$h_{67}(t) = h_6(t) * h_7(t)$; et

$w(t) = x(t) * h_{67}(t)$; cette sortie devient tout simplement :

$$y(t) = w(t) * h_4(t) + n(t) \tag{18}$$

Pour trouver $h_4(t)$, la RI du couplage acoustique, il suffit de filtrer $y(t)$ dans un filtre $f(t)$ de fenêtre finie tel que $f(t) * y(t)$, approxime $h_4(t)$ sans augmenter l'effet de $n(t)$ et sous certains critères d'optimalité.

Cette façon de formuler ramène donc le problème de la mesure d'une RI à celui de trouver le filtre $f(t)$.

On cherche l'équation du filtre $f(t)$ par la méthode basée sur des critères des moindres carrés :

Erreur = $e = \sum [\, f(t) * y(t) - h_4(t)\,]^2$ minimale.

C'est-à-dire $f(t) * s_{22}(t) = s_{24}(t)$ (19)

D'autre part, en prenant la FAC de $y(t)$ donnée en (18), on a :

$$s_{22}(t) = s_{ww}(t) * s_{44}(t) + s_{nn}(t)$$

Et la FIC de $y(t)$ et $h_4(t)$ donne d'autre part :

$$s_{24}(t) = [w(t) * h_4(t) + n(t)] * h_4^{\#}(t) \quad ;$$

$$h^{\#}(t) = h^*(-t) \text{ fonction adjointe}$$

$$= w(t) * (h_4^{\#} * h_4)(t) + (n * h_4^{\#})(t)$$

Si $h_4(t)$ est considéré comme un processus à corrélation microscopique et $n(t)$ un bruit décorrélé, on a les égalités suivantes :

$$(h_4 * h_4^{\#})(t) = \delta(t) \ ;$$

$$(n * h_4^{\#})(t) = 0$$

Et comme $\delta(t) = \delta(-t)$, postulat dans la théorie de distributin de Dirac, cela donne pour la FIC :

$$s_{24}(t) = w(t) * \delta(-t) = w(-t) \qquad (20)$$

En combinant (18), (19) et (20), on a :

$$f(t) * [s_{ww}(t) + s_{nn}(t)] = w(-t)$$

Soit en fréquence, par transformation de Fourier :

$$F(\nu) \ . \ S_{ww}(\nu) + S_{nn}(\nu) = W^*(\nu)$$

D'où

$$F(\nu) = \frac{W^*(\nu)}{|W(\nu)|^2 + S_{nn}(\nu)}$$

$|W(\nu)|$ est le module de $W(\nu)$

Avec $S_{nn}(\nu)$ généralement considéré comme un terme constant.

CONCLUSION

Ce panorama a permis de montrer l'éventail des possibilités opérationnelles dont disposent les acousticiens pour effectuer la mesure d'une réponse impulsionnelle. Il n'est pas une étude comparative de techniques de mesure, mais un exposé de méthodologies. Ces techniques, dans le domaine d'acoustique, s'originent soit dans la métrologie fréquentielle, soit dans la métrologie temporelle. Toutefois, on constate actuellement que les conceptions théoriques de ces méthodes sont basées essentiellement sur des formulations temporelles : ce qui explique en partie le développement de la métrologie temporelle acoustique.

En acoustique moderne des salles, la réponse impulsionnelle, fonctionnelle propre du canal, peut être considérée aujourd'hui comme point de départ de toute étude conduisant à la caractérisation de tels systèmes : c'est pour cette raison que les acousticiens se polarisent sur cet opérateur, et que l'on recommande habituellement de le déterminer avec un soin tout particulier. Mais le problème est que la plupart des modèles théoriques sur lesquels sont fondées ces techniques de mesure sont soit trop idéalisés (indépendance statistique des signaux), soit trop simplifiés (globalisation de la réponse impulsionnelle) ; ce qui pose ici naturellement le problème de la "finesse de représentativité" de cet opérateur.

L'approche méthodologique proposée par BERKHOUT, DE VRIES et BOONE [9] semble intéressante sur le plan de la globalisation de la réponse impulsionnelle, ce qui nous a incité, dans le cadre de ce panorama, à en rappeler la formalisation mathématiquèe au paragraphe II.2.3. Sur le plan conceptuel, l'intérêt d'une telle approche est qu'elle permet théoriquement d'obtenir uniquement la réponse impulsionnelle propre (utile) du système à mesurer ; ceci contrairement aux autres techniques qui donnent une réponse impulsionnelle "globale" c'est-à-dire incluant le couplage acoustique et les éléments constitutifs de la chaîne de mesure.

Enfin, aucun critère de choix d'une méthode n'est suggéré dans cette synthèse, car nous pensons que cela doit dépendre des moyens matériels disponibles et surtout du degré de familiarisation de l'utilisateur avec une technique donnée.

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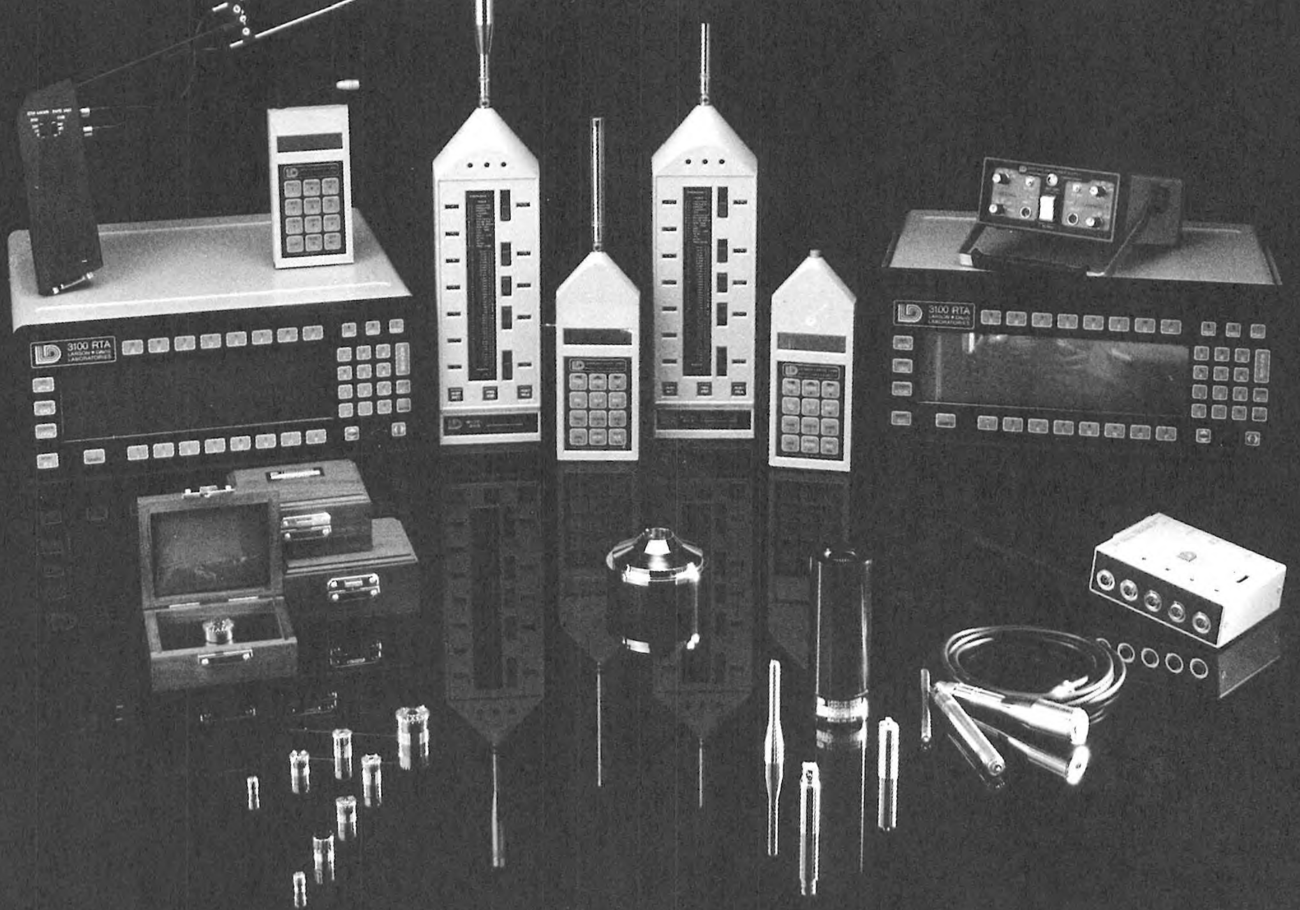
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THE EFFECT OF NON-UNIFORM INSERT PITCH ON NOISE GENERATION DURING FACE MILLING OPERATIONS

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ABSTRACT

Excessive noise generation often occurs during the face milling of certain thin-walled aluminum workpieces. Theoretically such noise can be reduced by utilizing milling cutters which employ non-uniform insert pitch. This study reports on the results of a series of tests undertaken to determine the noise reduction potential of four different non-uniform pitch cutters used to machine the engine mounting face of an aluminum transmission housing. It is shown that the use of non-uniform insert pitch does not necessarily reduce overall noise generation. There is, however, often a reduction in "noisiness". The difficulties of applying existing "quiet" cutter design principles to workpieces of complex geometry are also discussed.

SOMMAIRE

Très souvent, lors de l'usinage en plan de certaines pièces d'aluminium de faible épaisseur, un niveau de bruit excessif est constaté. Théoriquement, ce bruit peut être atténué par l'utilization de fraises dont les couteaux sont répartis de manière non-uniforme sur la périphérie. La présente étude rend compte des résultats obtenus lors d'une série d'expérimentations menées afin de déterminer la capacité réductrice de bruit de quatre différentes fraises à répartition non-uniforme. Ces fraises ont été testées lors de l'usinage de la surface d'assemblage avec le moteur du carter d'une transmission. Ces expérimentations ont permis de constater que l'utilization de fraises à répartition non-uniforme ne réduit pas forcément le bruit généré. Toutefois, on remarque que le caractère "gênant" due bruit est souvent atténué sensiblement. Ajoutons que l'étude a aussi porté sur les difficultés rencontrées lors de l'application des principes de conception de ces outils "silencieux" à l'usinage de pièces de géométrie complexe.

INTRODUCTION

In recent years significant progress has been made in reducing noise levels generated during the operation of high volume, multistation transfer machines. Generally, these reductions have resulted from the demands of purchasers who must meet government legislated limits and who also wish to avoid the economic penalties associated with claims for hearing damage compensation. Yet, in spite of these improvements, there still exists the need for further decreases in machine noise levels.

Transfer machines consist of many automatic machine tools which are interconnected by a central transfer spine. The workpieces, generally mounted on pallets, which act as the machining fixtures, are moved sequentially from one tool, or "station", to the next. This process is intended to meet high production requirements and, as such, is used extensively in the transportation industry.

The relatively recent thrust made by the transportation industry toward lighter, more fuel efficient vehicles, has meant that the machine tool industry must often machine thin-walled, light-weight castings on high-volume, transfer-lines. In addition, the need to reduce unit costs has led to demands for substantially increased production rates.

Thus, manufacturers of transfer lines are presently confronted with the need to produce machines which cut more metal faster, from relatively more compliant parts, than has previously been the case. Unfortunately, this often results in the generation of excessive noise levels during the machining cycle. In the particular case of aluminum transmission housings, the combination of high cutting speeds, thin walls and bell-like geometry can result in excessive noise generation during the face milling process. Sound levels as high as 118 dBA have been measured at a distance of 3 m from actual production machinery. The generation of such noise levels makes it extremely difficult for manufacturers to meet existing occupational noise exposure limits. The fact that many jurisdictions are presently contemplating a further tightening of noise regulations, will only compound these difficulties. If machines cannot be produced to meet present and future noise limits, then both machine tool users and builders are likely to suffer significant economic penalties.

Face milling is a very common machining process during which a flat surface is generated progressively by the removal of small amounts of material ("chips") as the rotating milling cutter is fed across the stationary workpiece. It is, of course, possible to move the workpiece under a stationary milling cutter, however this is normally not done on transfer machines due to fixturing restrictions.

In all practical cases, multiple-tooth cutters are used to provide high metal removal rates. Often the desired surface may be obtained in a single pass of the cutter and since excellent surface finish can be obtained, face milling is particularly well suited, and widely used, for mass production machining systems.

The face milling cutter itself consists of a cylindrical, steel body containing cutting inserts ("teeth") which intermittently engage and cut the workpiece. See Figure 1. Most commonly, the inserts are evenly spaced around the periphery of the cutter body. Their orientation means that the cutting action occurs on both the periphery and "face" of the milling cutter. It is for this reason that the process is known as face milling. The inserts are usually made from carbide or ceramic materials. In most high volume applications the inserts are clamped in the body and are "indexable". That is, when one cutting edge is damaged the insert may be unclamped, removed from the cutter body, reoriented ("indexed"), and then reinstalled with one of its remaining sharp edges in position to resume machining. When all cutting edges have been used on a particular insert, it is thrown away and replaced with a new one. The fact that only the inserts must be replaced, and not the complete milling cutter, has obvious economic advantages.

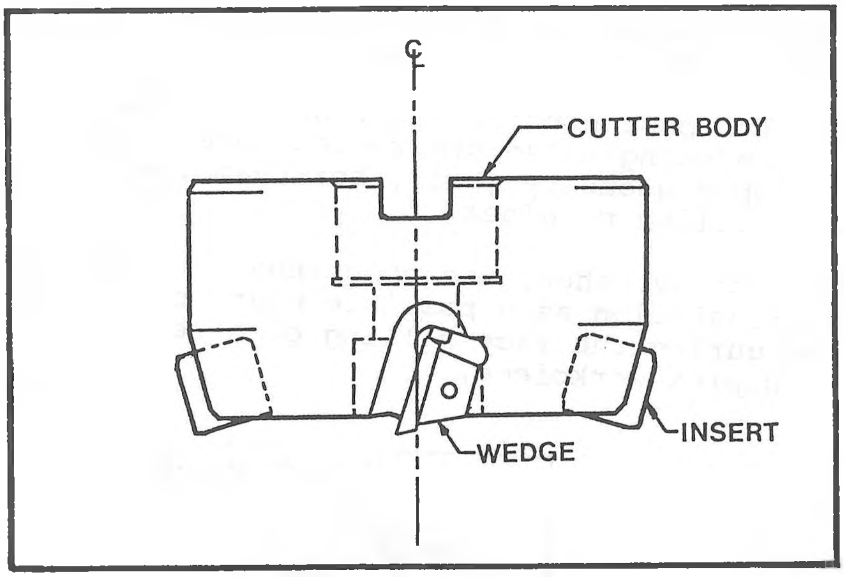

Figure 1. An indexable insert face milling cutter.

Experience has shown that during face milling of relatively compliant workpieces, such as an aluminum transmission housing, it is the workpiece itself, and not the machine structure or the milling cutter body, which is the primary radiator of noise.

Although it is theoretically possible to reduce the noise generated during the milling process by employing damping pads [1], enclosures [2], or other peripheral methods, the practical problems of additional cost, space limitations, maintenance difficulties, workpiece deflections, etc. make these solutions generally unattractive.

The reduction of workpiece vibration, and hence noise, at its source is, in every respect, the most desirable solution. This can best be achieved by modifying the milling cutter in such a manner as to minimize the workpiece response to the excitation imparted by the milling cutter insert engagements.

Studies by various researchers have indicated that the non-uniform spacing of events in a multi-event cycle has the potential to reduce vibration and noise generation. Varterasian [3] showed the efficacy of this general procedure when applied to snow tire noise reduction. Also, Ewald et.al. [4], Krishnappa [5] and Segawa [6] have shown that the same principle can be employed successfully in fan design. Doolan et. al. [7], [8] and Burney and Wu [9] have demonstrated such a technique for use with milling cutters. Applied to face milling cutters, this technique results in an irregular cutting insert pitch. Such an approach is highly attractive since it attacks the source of the noise generation without recourse to expensive and difficult-to-maintain control methodologies. There would be essentially no cost penalty associated with the production of a face mill with non-constant insert pitch relative to the familiar cutter with uniformlly spaced inserts.

Unfortunately, most studies describing the use of non-constant insert pitch in reducing noise generation have been concerned with workpieces of simple geometry (bars, box-beams, etc.) using small, single-purpose, milling machines.

The present study, then, was concerned with the application of insert spacing modulation as a possible means of reducing the noise levels produced during the face milling of a relatively compliant, geometrically complex workpiece.

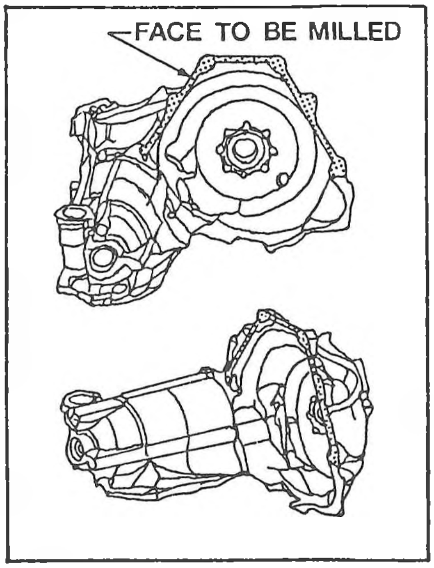

Figure 2. Two views of the transmission case.

METHODOLOGY

All tests were conducted during the machining of the engine ounting face of a cast aluminum, automobile transmission case. The ocation of this face on the transmission case is shown in Figure 2. he engine mounting face is geometrically "complex" as it results in ontinuous variation of the insert entrance and exit angles, and in he effective width of cut. The path followed by the face milling utter during each machining cycle is shown in Figure 3.

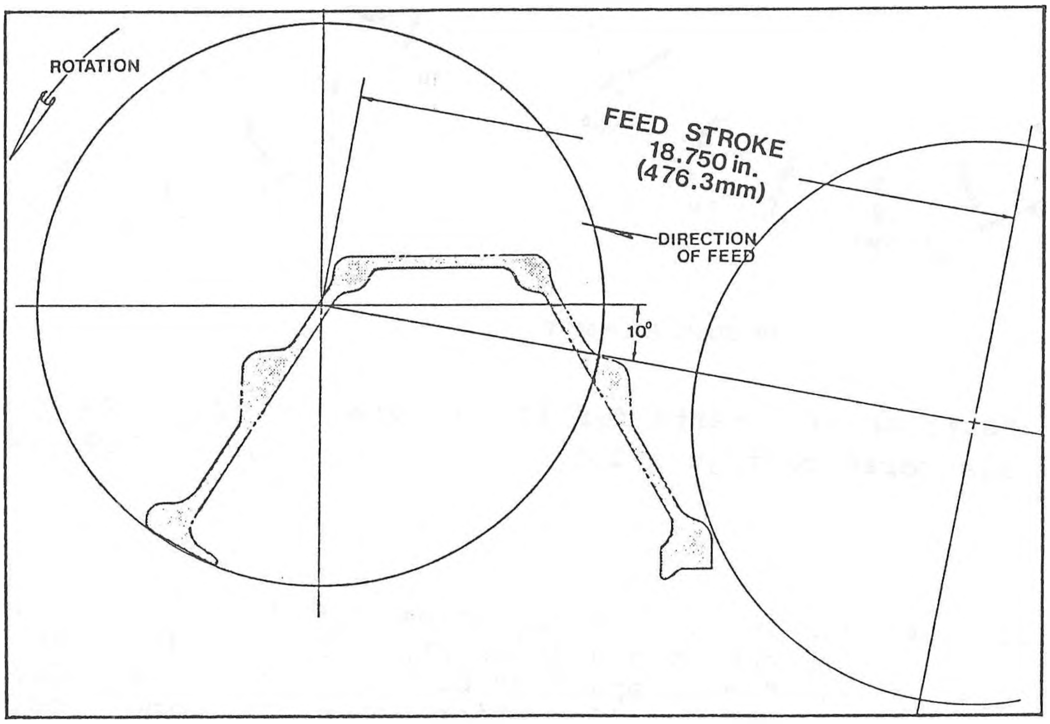

Figure 3. Relationship between the part profile and cutter path.

A total of five different cutter configurations, all with cutting eighteen indexable inserts, were employed in this study.

The tooling consisted of the following three cutter bodies:

i) A Valenite 406 mm diameter ring-type cutter with equally spaced insert pockets.

ii) A Valenite 406 mm diameter ring-type cutter with a 1° staggered pocket configuration. This cutter employed standard (unmodified) inserts. This configuration is designated "1° STAG" in this paper. See Figure 4.

iii) A Valenite 406 mm diameter ring-type cutter with a 1/2° staggered pocket configuration. The cutter employed standard inserts. This configuration is designated as "1/2° STAG" in this paper. See Figure 5.

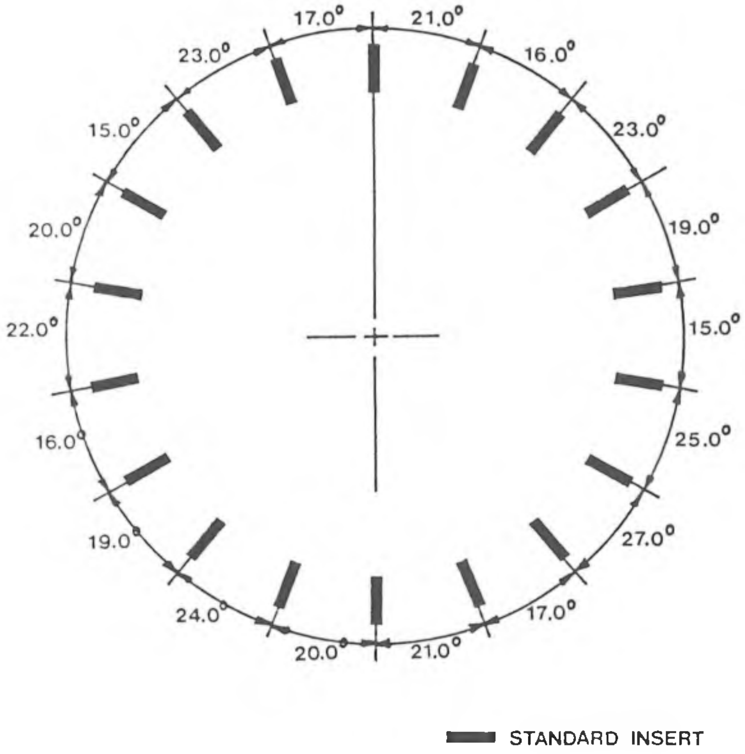

Figure 4. Position of inserts for 1° staggered configuration.

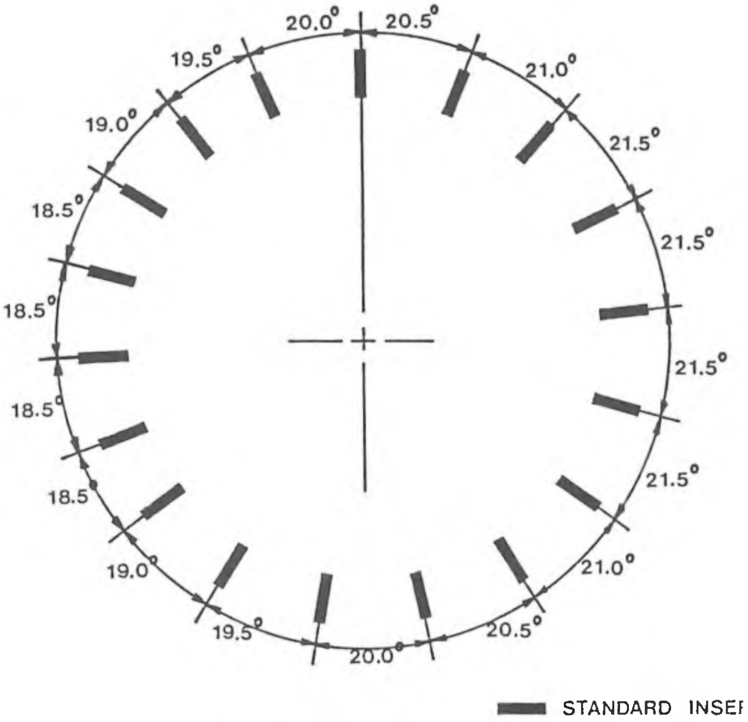

Figure 5. Position of inserts for 1/2° staggered configuration

Insert pockets in all cutter bodies provided a 10° positive axial and radial rake for the standard inserts. In two cases the standard inserts used in the "equal spacing" cutter body were modified to provide a total of three configurations from this single cutter body:

i) Standard inserts set into the equally spaced pockets. This configuration is designated as "EQ. SP.".

ii) Five standard inserts were modified by grinding them back 1.5 mm and installed at randomly chosen positions. The remainder of the pockets employed standard inserts. This configuration is referred to as "EQ. SP. 5 GR." in this paper. See Figure 6.

iii) Five standard inserts were modified by grinding with a 1.5 mm smaller inscribed circle (I.C.) and installed at the same positions as in (ii) above. The remainder of the pockets employed standard inserts. This configuration is designated "EQ. SP. 5 I.C.". See Figure 6.

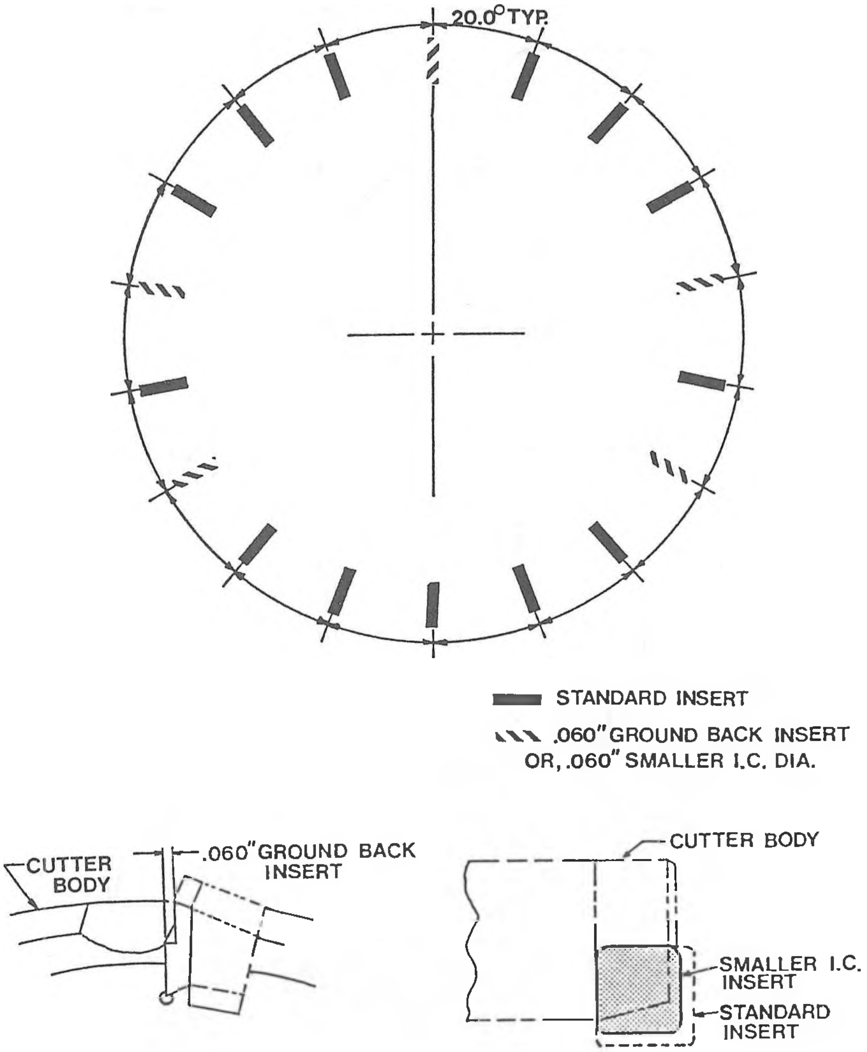

Figure 6. **Position of inserts for equally spaced configuration with either five inserts ground back or five inserts with smaller inscribed circle.**

The "1° STAG" and "1/2° STAG" configurations were chosen as representative of the design approach suggested by Vanherck [10] and Varterasian [11]. Basically, the insert spacing approximates a sinusoidal variation around the cutter. This can be seen quite clearly in Figure 7. In this figure the ratio of the actual pitch in degrees to the average pitch in degrees is plotted for each tooth. For the case of the "1/2° STAG" cutter the variation is reasonably smooth. For the "1° STAG" cutter the variation is much coarser with multiple crossings of the "EQ. SP." line. Obviously, on such plots a cutter with equally spaced inserts will be represented by a horizontal straight line, since each insert will have the same L/L_{avg} value. Note that the solid lines joining the points on these figures are used only to enhance the pattern formed by the plotted points and do not signify the existence of a continuous relationship between these points.

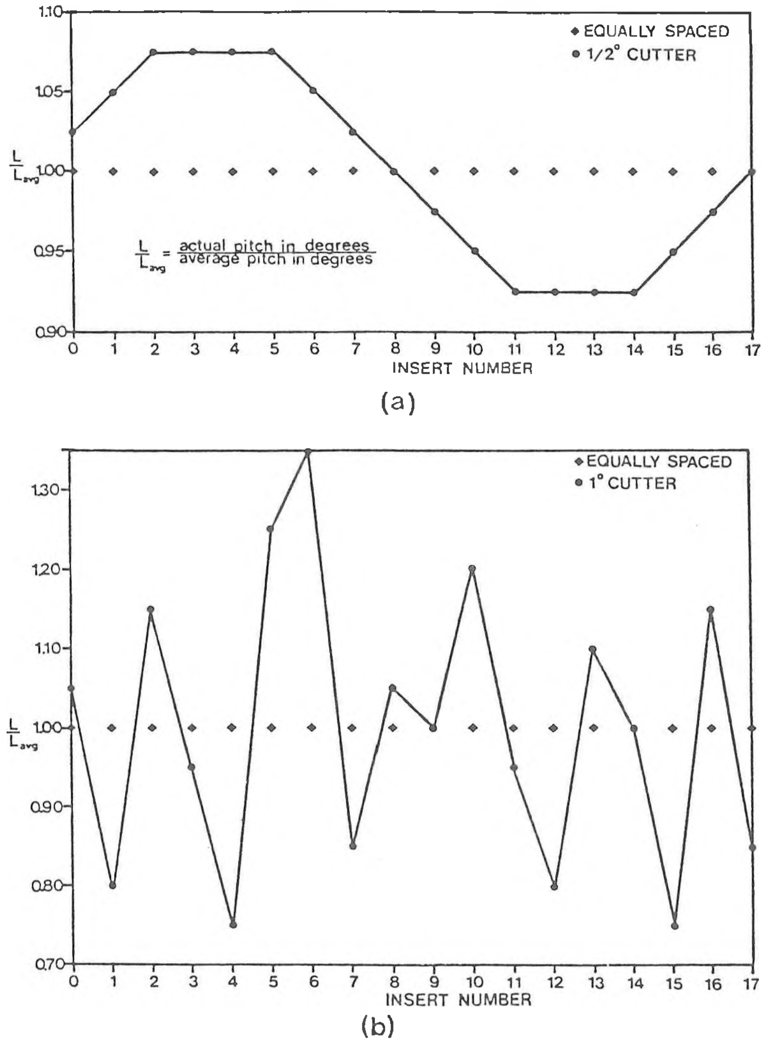

Figure 7. Plot of insert spacing for, (a) 1/2° STAG, or (b) 1° STAG.

The cutter configurations "EQ. SP. 5GR" and "EQ. SP. 5IC" were based on techniques employed by Reif [12] so successfully in a previous field application. In the present case it was hoped to determine whether small random perturbations of the cutting edges guarantee a reduction in noise relative to the evenly spaced configuration. It is generally agreed [13] that any change from even spacing improves the chatter resistance of a face milling cutter; however, it has not been shown that simple, random variations in insert pitch always result in noise reductions. These cutters were expected to help clarify the situation.

The "EQ. SP." configuration was employed as the "control" against which the results from the other cutters would be compared. This configuration is the industry standard, although there are some non-uniform pitch cutters presently in volume production, primarily to increase chatter resistance.

The cutter spindle rotated at 967 rpm for all tests. This translates into a surface speed of 21 m/s and a feed per tooth of approximately 0.2 mm for the equally spaced cutter. These are quite conservative values and would not be expected to put undue stress on the cutting inserts. They are, in fact, indicative of values which might be chosen for the production situation where reasonable tooth life would be desired.

During the test sequences, the sound levels generated throughout the entire 9.4 second cutting process were tape recorded for later analysis. Each noise measurement was obtained at the same position along an unobstructed line of sight to the workpiece. Samples of both the background and idle (spindle rotating but not cutting) noise levels were recorded for use in "correcting" the cutting noise levels. Measurements were made for each milling cutter configuration at seven depths of cut, from 2.1 mm to 3.6 mm. All noise measurements were made on the actual high-volume transfer machine during the "run-off" period and were A-weighted. Calibration signals were recorded both at the beginning and end of each test sequence.

RESULTS

To permit comparison of the effect of the various cutter configurations on cutting noise levels, the Leq value for each trial cut was calculated and the results summarized in Table 1. The blanks in the table indicate measurements which for various reasons (equipment failure, set-up difficulties, etc.) were not ultimately obtained although they were initially planned.

SPINDLE SPEED 967 rpm

	DEPTH OF CUT - in. (mm)						
CUTTER	0.083 (2.1)	0.093 (2.4)	0.103 (2.6)	0.113 (2.9)	0.123 (3.1)	0.133 (3.4)	0.143 (3.6)
EQ. SP.	88	88	88	89	90	91	92
EQ. SP. 5GF	88	89	89	90	90	93	93
1° STAG.	90	91	92	92	92	94	94
1/2° STAG.	-	92	-	91	92	92	93
EQ.SP. 5IC.	92	92	92	93	93	93	-

Table 1. Summary of the L_{eq} values obtained during the test sequences.

A review of the data contained in Table 1 indicates that the four milling cutters employing non-uniform insert spacing generated noise levels similar to, or higher than those of the equally spaced control. For all five cutter designs the noise level increased with depth of cut, although both the "1/2° STAG" and "EQ. SP. 5 I.C." configurations seem to indicate less sensitivity to this variable over the range studied. See Figure 8.

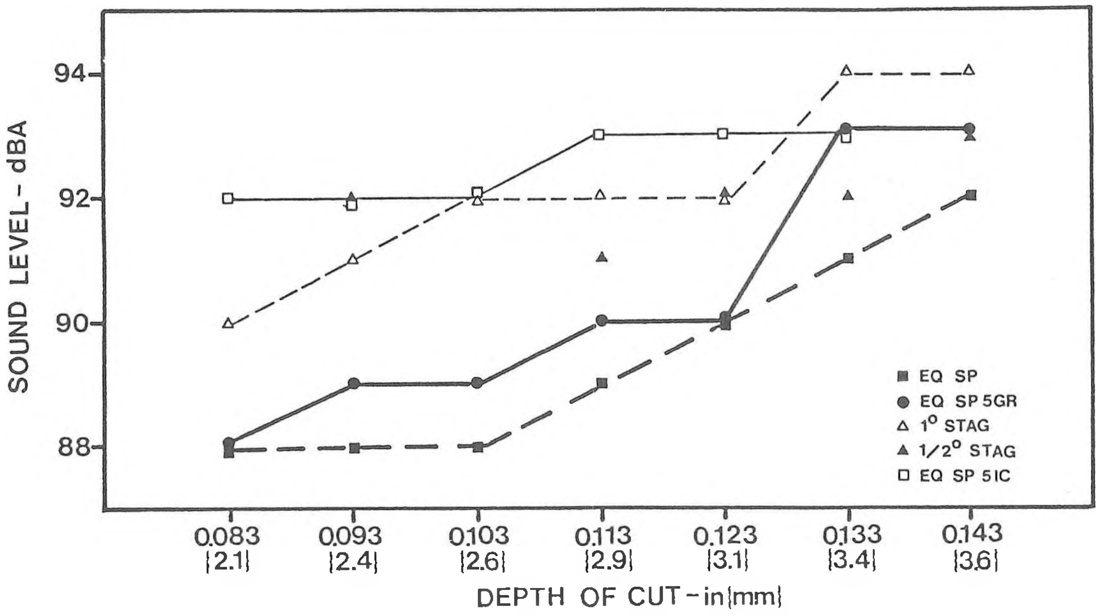

Figure 8. Energy equivalent sound level versus depth of cut.

Frequency spectra of the noise generated by each cutter design indicate that the non-uniform insert pitch caused redistribution of the sound energy over a wider bandwidth when compared with the equally spaced cutter. This phenomenon is illustrated in Figure 9. In this instance, Test #24 and Test #25 produced the same Leq value, yet the redistribution of energy due to the non-uniform pitch employed in Test #24 is readily apparent. The cursor shown marks the "EQ. SP." cutter's fundamental "insert engagement frequency" (frequency of cutter rotation x number of inserts) while the open circles mark the positions of the first fifteen higher harmonics of this fundamental frequency.

All frequency spectra in this paper are shown with the magnitudes of the components presented in the form of the dimensionless ratio p/p_r, where p is the r.m.s. sound pressure and p_r is the standardized reference pressure of 0.00002 Pascals.

It should be noted from Figure 9 that although no change in overall Leq value was achieved, Test #24 indicates a reduction in "noisiness" relative to Test #25 due to the significant decrease in sound energy concentrated at discrete and harmonically related components [14]. This result was not restricted to particular test groupings but was found to be generally applicable.

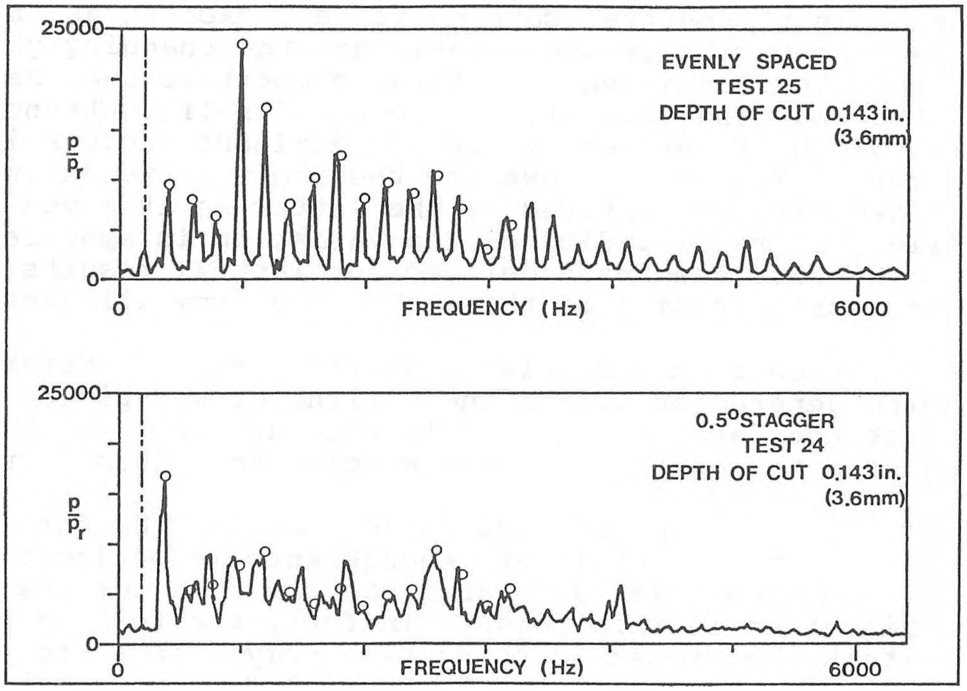

Figure 9. Comparison of spectra from two test cuts.

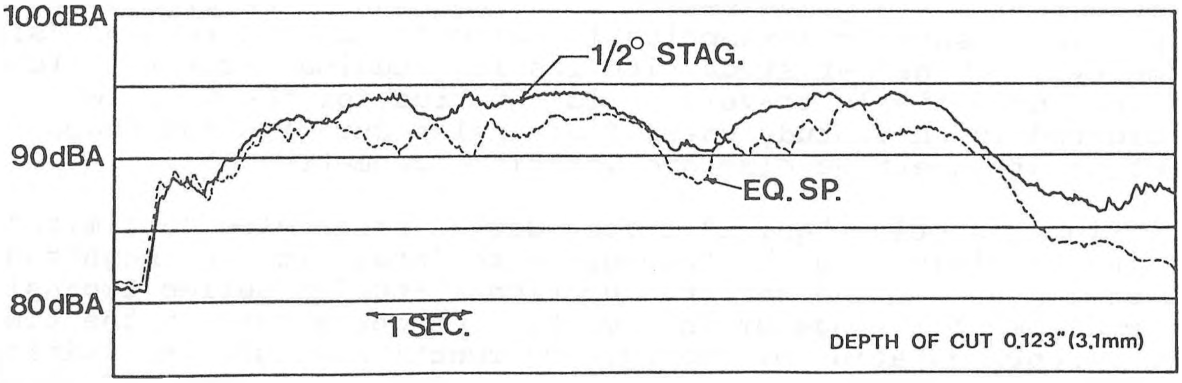

Figure 10. Comparison of sound levels generated by two different cutters.

A review of all the sound level-versus-time readings which were generated during the cutting tests of each milling tool indicates that, although unique, they do exhibit remarkable similarities. Figure 10 shows a comparison of the noise levels produced during Test #5 ("EQ. SP." cutter; depth of cut 3.1 mm) and Test #36 ("1/2 STAG" cutter; depth of cut 3.1 mm). These are significantly different cutter geometries and yet it is apparent that various common regimes of noise generation (characterized by changes in overall sound level and the predominant spectral components) are excited as the cutter moves across the part. It would seem that the changing geometry of the part (and its associated structural properties such as stiffness, etc.) and the changing geometry of the cut itself (entrance angle, exit angle, width of cut, etc.) are the dominant factors in producing these regimes. Figure 11 shows how the regimes are defined by the changes in geometry encountered by the cutter as it moves over the part profile. Figure 12 indicates the variation in spectral content for three arbitrary "regimes" defined for Test #1 results. Such results are representative of those obtained from all test sequences.

Certainly such phenomena play a critical role in determining the overall noise generation during the milling of workpieces of complex geometry, yet they are not adequately accounted for in the existing procedures used to determine insert spacing for "quiet" cutters.

Generally such design procedures assume that the forcing function associated with the cutter insert engagements is periodic within the cutter rotation when this is clearly not the case for the type of workpiece discussed in this paper. In fact, the forcing function is periodic within the process cutting time only. Thus, for our case of an 18 insert milling cutter, the "periodic" forcing function does not consist of 18 unique force pulses as existing design procedures would assume, but a total of 2,727 force pulses (total process cutting time in seconds x spindle r.p.s. x number of cutter inserts).

It is also normally assumed that the modulation of the force pulse durations within a given period is a function of cutting tooth spacing only. While such an assumption is valid for a workpiece of "simple" geometry (such as bar stock with its longitudinal axis set along the axis of the cutter's travel) it is not true for the workpiece considered in this study where force pulse duration and shape are a function of insert spacing and workpiece geometry.

Since existing "quiet" cutter design strategies "optimize" insert spacing by minimizing the "energy" associated with the magnitude of the components of the forcing function's Fourier Series Expansion (over a specific range of interest), then any errors in the time domain representation of the forcing function result in minimization of "energy" associated with the "wrong" Fourier Series. Consequently, this produces a cutter design which is not "optimal" (minimum noise generation) for the actual operating conditions.

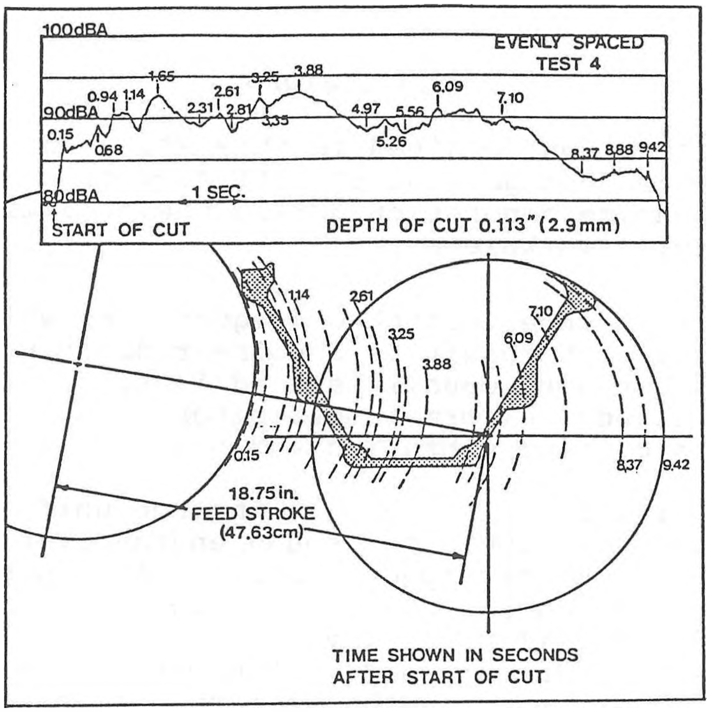

Figure 11. Sound level generation as a function of cutter position.

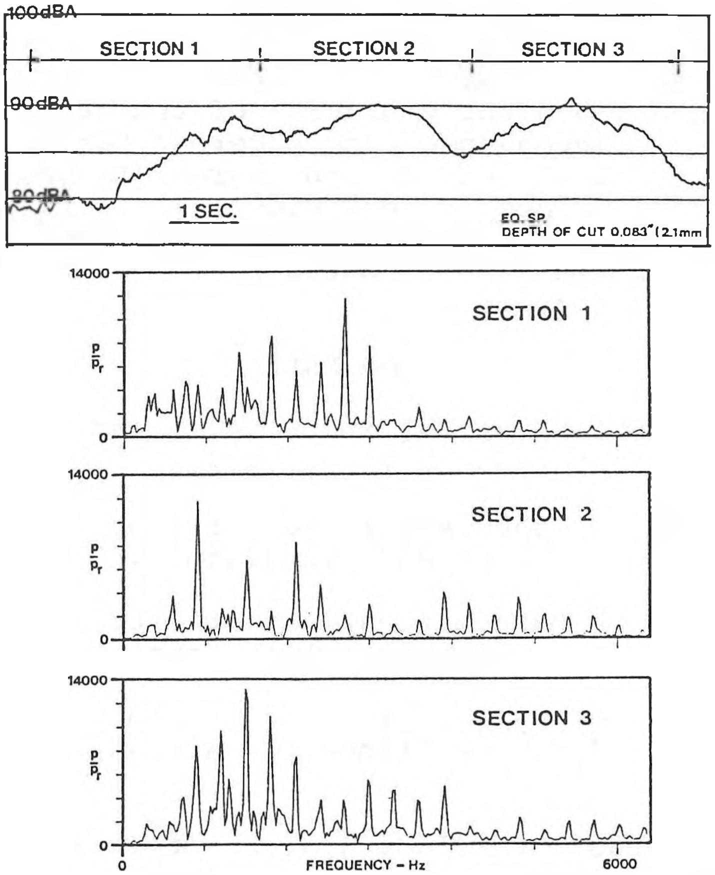

Figure 12. Comparison of the spectral content of three arbitrarily defined regimes.

CONCLUSIONS

From the information obtained in this study the following conclusions can be made regarding the efficacy of non-uniform insert pitch in reducing noise generation during the face milling of a geometrically complex workpiece.

i) The non-uniform insert pitch configurations which were used in this study did not result in a noise reduction relative to a standard cutter with equally spaced inserts. Thus it is apparent that non-uniform insert pitch does not guarantee a reduction in cutting vibration and noise.

ii) Spectral analysis indicated that the non-uniform insert pitch did in fact redistribute the sound energy over a wider bandwidth compared to the evenly spaced cutter. Although this rearrangement of energy was not sufficient to provide a reduction in overall noise level, it did provide a significant reduction in the "noisiness" of the cut. This was the result of a significant decrease in the magnitude of discrete, harmonically related components.

iii) The complex nature of the part geometry produced, during each cut, several well defined noise emission regimes, within each of which the overall level and noise spectrum are unique.

iv) It was evident that the predominant source of noise during the cutting process was the vibration of the workpiece. Its complexity and dependence upon numerous variables makes modifications to the excitation source (the milling cutter) the only practical method of reduction. It is equally evident that existing procedures for determining the unequal distribution of inserts to produce "quiet" cutters are not suited to workpieces of complex geometry.

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The Canadian Acoustical Association
l'Association Canadienne d'Acoustique

Call for Papers

ACOUSTICS WEEK IN CANADA, OCTOBER 1989

Acoustics Week in Canada will be held at the Chateau Halifax, Halifax, Nova Scotia from 16 to 19 October. The event will begin with two days of courses on topics including underwater acoustics, condominium acoustics and sound intensity, followed by a full technical program for two days.

The aim of the meeting is to provide opportunities for members of the Canadian Acoustical Association and other interested parties to exchange and share information about all aspects of acoustics. The convener of the meeting is Bob Cyr, Nova Scotia Power Corporation, P.O. Box 910 [or street address, 5261 Duke St., Duke Tower, Suite 418, Scotia Square] Halifax, Nova Scotia, B3J 2W5 (902) 424-6589. Margaret Cassidy who is serving as the Secretariat may also be contacted for further information at the same address, phone (902) 428-6214; FAX (902) 428-6100; Telex.: 019-21736.

Technical Program

Contributed structured paper sessions, individual papers and posters are invited from all areas of acoustics including but not restricted to architectural, underwater, industrial, environmental, physical, physiological, musical, psychological, noise control, ultrasonic and infrasonic acoustics.

Plans are being made for a special Plenary Invited Session on Weather Observation Through Ambient Noise (WOTAN) as well as Symposia on Underwater Acoustics, Speech Communication and Physiological Acoustics, among others.

Submissions will be refereed. To provide time for the review process and return of feedback to authors, *deadline for submission of abstracts and full papers is May 15, 1989.* It is not necessary to submit a full paper in order to participate in the program; an abstract will be acceptable. All accepted abstracts will be published in CANADIAN ACOUSTICS; accepted full papers will be published in the Proceedings.

Preparation of abstracts and papers

Abstracts. Four copies of an abstract must be submitted for each presentation, whether invited or contributed. Abstracts must be prepared in accordance with the enclosed Instructions for the Preparation of Abstracts. If the entire abstract does not fit on a single page with double-spaced typing, the abstract is too long.

Mail the *original and three copies* of the abstract to the Technical Program Chair:

Dr. A. J. Cohen, Department of Psychology, Dalhousie University, Halifax, Nova Scotia B3H 4J1, Telephone: (902) 424-8888. (Bitnet E-mail address is ACOHEN@DALAC).

Since the 15 May deadline for receipt of abstracts at the above address will be strictly enforced, it is the contributor's responsibility to ensure that the Technical Chairman receives the abstracts on or before then. Authors desiring notification of receipt of their abstract should include a stamped self-addressed postcard which will be returned when the abstract is received. Authors invited to participate in special sessions should send all materials to their particular special session organizer for receipt one week prior to the May 15 deadline.

A 35-mm slide projector and an overhead projector for transparencies will be available for all papers. Other audiovisual equipment may be requested and will be supplied if available.

Papers for Proceedings. For those wishing to submit a paper to be reviewed for publication in the Proceedings, send with the abstract, four copies of the paper. Feedback from reviewers and notification of acceptance will be sent to be received by the author before July 15. The deadline for the final version of the paper to be received in Halifax is August 26. Further details are provided on the final page of this Call for Papers.

Formats: Symposia, Lecture or Poster

Individuals or groups of individuals are encouraged to organize a Symposium or group of from four to eight papers structured around a particular theme (e.g., sound recording; industrial noise measurement). The collection of abstracts and papers for the symposium will be submittedby the symposium organizer for review as a complete package.

More typically, papers will be submitted independently, and will be grouped subsequently into appropriate categories for presentation.

Poster sessions will provide an alternative means of presenting work informally. Authors will be asked to stand by their posters during a certain time period in order that those interested may speak to him or her about the material. Details for production of the Poster will follow upon acceptance of the abstract.

Student Awards

There will be up to three awards of $500 made for the best contributions by students as judged by the Canadian Acoustical Association Meeting Awards Committee. The award is based on both oral presentation and submitted paper. Student papers must be presented as a lecture. The paper may be jointly authored, but the student must be the first author on the paper. Students must be currently enrolled in undergraduate, or graduate programs on May 1, 1989.

Exhibit

Exhibitors will also be on hand displaying the latest in instrumentation, materials and technology. For further information contact: Margaret Cassidy (address, previous page).

Social Program

On October 17, a trip to scenic Peggy's Cove in the afternoon and an evening at a local dinner theatre featuring music and entertainment of the 60's is planned. On Oct. 18, the Annual CAA banquet will be held. Following the conference, a field trip to the Alexander Graham Bell Museum in Baddeck, Cape Breton is tentatively scheduled.

Instructions for the Preparation of Abstracts for Papers to be Presented at the 1989 Meeting of the Canadian Acoustical Association

1. Quadruplicate copies of an abstract are required for each meeting paper; one copy should be an original. Send the four copies to the Technical Program Chairperson, Annabel J. Cohen, Dept. of Psychology, Dalhousie University, Halifax, N. S. B3H 4J1, in time to be received by **May 15, 1989.** Either English or French may be used. A cover letter is not necessary.

2. Limit the abstract to 200 words, including title and first author's name and address; names and addresses of coauthors are not counted. Display formulas set apart from the text are counted as 40 words. Do not use the forms "I" and "we"; use passive instead.

3. Use the sample format shown on the reverse side of these instructions. Title of abstract and names and addresses of authors should be set apart from the abstract as shown. Text of abstract should be one single, indented paragraph. The entire abstract should be typed *double spaced on one side* of 8 1/2 x 11-in or A4 paper.

4. Be sure that the mailing address of the author to receive the acceptance notice is complete on the abstract, to insure timely deliveries.

5. Do not use footnotes. Use square brackets to cite references or acknowledgements. Give references as shown in the example on the reverse side.

6. Underline nothing except what you wish to be italicized.

7. If the letter is used as a symbol in a formula, loop the letter l by hand and write "lc ell" in the margin of the abstract. Do not intersperse the capital letter O with numbers where it might be confused with zero, but if unavoidable, write "capital oh" in the margin. Identify phonetic symbols by appropriate marginal remarks.

8. At the bottom of an abstract give the following information:

   (a) If the paper is part of a special session, indicate the session. If invited, state, "invited".
   (b) Name the area of acoustics most appropriate to the subject matter: Architectural Acoustics, Bioresponse to Vibration, Environmental, Industrial, Infrasonics, Musical, Noise Control, Physiological, Psychoacoustics, Speech Communication, Ultrasonics, Underwater Acoustics, or other.
   (c) Telephone number, including area code, of the author to be contacted for information. Non-Canadian authors should include country.
   (d) If more than one author, name the one to receive the acceptance notice.
   (e) Overhead projectors and 35-mm slide projectors will be available at all sessions. Describe on the abstract itself any special equipment needed.
   (f) Indicate your preference to present a lecture or poster.

[Adapted from Acoustical Society of America Guidelines]

A survey of new facilities for measurement of x. John S. Doe and Jane S. Smith. (X Ltd., 90 X Ave., XCity, Ont. LXL 9X9).

The measurement of x and the changes in the shape of y during z has been a persistent problem for x scientists. In recent years a number of new techniques have become available for measuring x and y and this paper will briefly survey some of these. Included will be a description of (a) the M Institute of N super microbeam project, ...etc..... (b).......... ....(c).. text ....more text... ....text (not more than 200 words) ....(d).......................etc.. .... This concurs with an earlier report [J.S. Someone and J.S. Someoneelse, Canadian Journal of X and Y, 14, 31-35, (1985)]. It is suggested that because of a, b is the most practical approach to x in most situations. [Work supported by ZZZ Foundation].

Technical area: Speech Communication

Method of Presentation: Prefer lecture but willing to give as poster

Telephone number: 418/555-7897 Ext. 481 (J.S. Doe)

Send acceptance or rejection notice to J.S. Doe

Special facility: VHS video tape player, cassette audio tape player, amplifier and speakers

SEE OVER FOR INSTRUCTIONS

Instructions for the Preparation of a Full Paper For Publication in the Proceedings of the Meeting

The paper will elaborate the material in the abstract and will be written under the same style constraints as described in the Instructions for Preparation of an Abstract and will be submitted in triplicate.

The maximum length including figures and references but excluding the abstract is 10 double-spaced pages.

Complete references (date, author's initials and final name, publication, volume, and pages) to material cited in the text should be given at the end of the paper.

Papers will be submitted to reviewers (normally two) who will provide feedback to the author as well as commendations regarding acceptability for publication. The author will subsequently be provided the opportunity of revising the paper (if necessary) for final submission for publication in the Proceedings. There will be a separate review committee of experts for each area of acoustics.

Please note, it is not necessary to submit a full paper in order for your work to be considered for presentation at the meeting. The submission of the full paper provides an opportunity for additional dissemination of your work as well as for feedback from reviewers. A full paper may be submitted for either lecture or poster presentation format.

To be considered for a student award, a full paper must be submitted with the student as first author. Additional coauthors are permissable and will not jeopardize the candidate in any way.

In order to increase the representativeness of the Proceedings, all authors are encouraged to submit a full paper.

Final versions of accepted manuscripts can be sent on IBM-PC (or compatible) or Macintosh floppy disks in ASCII format to expedite the printing and formatting of the Proceedings. Details will be made available upon acceptance of the paper, but authors are encouraged to use word-processing facilities rather than a typewriter at the initial stages of preparation of the manuscript if such an option is available to them.


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CANADIAN ACOUSTICAL ASSOCIATION
MINUTES OF THE BOARD OF DIRECTORS MEETING

October 5, 1988 - Trafalgar Room, Westbury Hotel
6:37 p.m. - Toronto, Ontario

Present:	S.M. Abel
	A.J. Cohen
	L. Cuddy
	B. Dunn
	R. Hetu
	N. Lalande
	J.G. Migneron
	M.M. Osman
	C. Sherry
	W.V. Sydenborgh
	E.A.G. Shaw (Invited)
	T.F.W. Embleton (Invited)
Absent:	C. Andrew
	G. Faulkner
	J. Nicolas

1. President's Opening Remarks — Sharon Abel

After thanking the attendees, the President presented some statistics related to 1988 membership update. A letter from Peter Vermeulen who chaired the CAA 1987 meeting in Calgary was read, indicating that he would soon be able to close the account and send any profits to the Treasurer.

2. Report of the Secretary — Moustafa Osman

Activities during 1988 included preparation and mailing of renewal forms and official receipts.

Based on comments from members of CAA, a favourable change to the National Building Code was communicated.

3. Report of the Treasurer — Sharon Abel on behalf of Chris Andrew

A statement from the Treasurer was read by the President. The need for professional services to help the Treasurer carry out his responsibilities was discussed.

It was decided that Bruce Dunn will present a motion during the annual meeting to allocate $2,000 for auditing and $1,000 for accounting.

Chris Andrew noted in his report that the status of CAA as a charitable organization will be investigated.

ACTION — Chris Andrew

4. Report of the Membership Chairman Annabel Cohen

A report on the activities of the membership committee was circulated. Ways of maintaining and increasing membership were discussed.

It was agreed that a budget of $600 should be allocated for printing CAA stationery.

5. Report of the Editor Raymond Hetu

A short report was discussed and in particular the use of the new CAA logo in Canadian Acoustics. Efforts to enhance the quality of material presented (Invited papers, etc.) and coverage of events (Column for News/Information) were commended.

6. Reports of Chairmen of Subcommittees on Prizes

a) Directors' Awards Nicole Lalande

The professional and student category awards were announced. Difficulties that were encountered in defining the eligibility for the student prize category were discussed.

b) Postdoctoral Prize Bruce Dunn, Lola Cuddy

A committee has been formed to investigate the conditions for this prize. A draft document was promised for the Spring of 1989.

c) Bell Prize Raymond Hetu

Contact has been made with Paul Mermelstein regarding the general requirements for this prize. It was hoped that a draft document would be available for discussion at the next Directors' meeting (Sping of 1989).

d) Underwater Acoustic Prize Sharon Abel

A letter from Harold Merklinger regarding this prize and involving how to finance it was read and discussed. It was agreed that Harold Merklinger should be invited to form a subcommittee to discuss conditions for the award.

e) Students' Presentations Winston Sydenborgh

A committee of two was formed (Aubry Edwards and Tom Northwood) to evaluate the presentations and choose the winners at CAA 1988 - Toronto.

f) Youth Science Foundation Annabel Cohen

Joining other organizations to offer pre-university students prizes in specific fields was discussed. A student prize of $300 for 3 years was agreed on.

7. Report of the Chairman for CAA '88 Winston Sydenborgh

It was reported that approximately 61 people had pre-registered were reported. Some seminars seemed to be more successful than others. A projected $30,000 revenue and $26,000 expenses is expected.

8. Report of the Chairman for CAA '89 Annabel Cohen

It was announced that Bob Cyr will be the Chairman for this event which will take place at the Chateau Halifax on October 15-19, 1989.

It was discussed and agreed that the host city for CAA '90 will be in Quebec, and possibly Montreal.

9. Report of the Past President Cameron Sherry

All officers accepted to remain for another year. Two directors position will become vacant (Lola Cuddy and Jean Nicolas). One possible candidate Tony Embleton, was discussed.

10. Affiliations: INCE, National Consortium Sharon Abel

It was decided to withdraw our membership from the National Consortium of Scientific and Educational Societies. It was agreed that INCE would be discussed under the next item.

11. Other Business

a) 12th ICA Edgar Shaw

A final report from the 12th ICA Executive Committee was circulated. The report included the auditor's report.

11. Other Business (contd)

The price for the remaining proceedings was discussed and it was agreed that these should be sold at the following rates:

$25 + postage + packing for North America and
$35 + postage + packing for overseas.

[At time of writing this report these prices including postage + packing are $50 and $60, respectively.]

MOTION It is moved that the 12th ICA Executive Committee be discharged.

Moved: Winston Sydenborgh Seconder: Raymond Hetu Carried

b) 1992 Inter-Noise Tony Embleton

Communication between Tony Embleton and I/INCE were discussed, especially the possibility of holding 1992 Inter-Noise in Canada.

c) CAA Honorary Members Winston Sydenborgh

Means to offer privilege(s) to individuals with over 25 years of membership were discussed. A subcommittee will be formed to investigate the matter.

d) Communications with Hugh Jones Sharon Abel

A letter from Hugh Jones regarding the size of noise control work relative to other acoustical subjects in the yearly symposium and event, was discussed. The Board did not believe that there were inequities.

e) Industrial Noise Control Manual Cameron Sherry

An announcement in Canadian Acoustics will be made regarding the remaining issues of this manual.

Meeting was adjourned at 9:45 p.m.

PREPARED BY:

M.M. Osman
CAA - Secretary
December 1988

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EXIT

MINUTES OF CANADIAN ACOUSTICAL ASSOCIATION
ANNUAL MEETING - 1988

The meeting was called to order at 4:29 p.m. on October 6, 1988 at the Westbury Hotel, Hall C, Toronto, Ontario. Thirty-three members were present.

1. Introductory Remarks — Sharon Abel, President

Welcome to Toronto and to the meeting.

2. Minutes of 1987 Annual Meeting — Sharon Abel

The minutes of 1987 Annual meeting were published in the March 1988 Canadian Acoustics issue pp. 45-49.

MOTION: That the Minutes of the 1987 meeting be accepted as printed.

MOVED: Tom Northwood Seconded: Cameron Sherry Carried

3. Business Arising from Previous Minutes — Sharon Abel

a) 12th ICA and Symposium

MOTION: That the 12th ICA Executive Committee be discharged.

MOVED: Alberto Behar Seconded: Bruce Dunn Carried

A financial statement and a report from Dr. E.A.G. Shaw had been pre-circulated to the CAA Board of Directors.

b) CAA '87 Acoustics Week, Calgary

This event was moderately profitable and the revenue will be forwarded to CAA, as soon as the account is closed.

c) Membership to NCSES (The National Consortium of Scientific and Educational Societies)

At the advice of CAA liaison officer Dr. J. Bradley, the CAA Board of Directors has decided to withdraw from its membership.

4. Officers' Reports

a) Secretary (Moustafa Osman):

Activities associated with membership mailings and changes to the National Building Code were reported.

MOTION: That the 1989 annual membership dues be confirmed as follows: $100 sustaining, $20 regular, $5 student.

MOVED: Bruce Dunn Seconded: Edgar Shaw Carried

b) Treasurer (Sharon Abel on behalf of Chris Andrew)

An interim financial statement was received from the Treasurer.

MOTION: That the Treasurer be allowed up to $3,000 in 1989 to secure professional services for auditing purposes.

MOVED: Bruce Dunn Seconded: Richard Peppin Carried

c) Membership (Annabel Cohen)

The activities of the membership office including the creation of local committees were presented.

MOTION: That the budget of the the Membership office be increased by $600 until December 1989 to print stationery.

MOVED: Annabel Cohen Seconded: Bruce Dunn Carried

d) Editor (Raymond Hetu)

A short report was delivered and the need for more papers communicated.

(General applause reflecting satisfaction with the enhanced quality of the material and appearance of the journal.)

5. Awards

Nicole Lalande announced the winners for 1987 Directors' Award ($500 each): Raymond Hetu in the professional category and D.C. Stredulinsky in the student category.

The guidelines for the post-doctoral award ($3,000) will be announced in the spring/summer of 1989 by Bruce Dunn.

Two prizes will be announced in the future, one in underwater acoustics and the other in speech and communications (Bell prize).

6. CAA, 1988 Winston Sydenborgh

About 100-130 people attended the various activities and a surplus is anticipated.

7. CAA, 1989 Annabel Cohen

This event will be held at Chateau Halifax on October 15-19, 1989.

8. Future Meeting Sharon Abel

It was announced that the 1990 CAA will hold its Acoustic Week in Quebec.

9. Report of Nominating Committee Cameron Sherry

All CAA officers have been asked and will continue to serve for another year.

Two nominations for the Board of Directors were presented (Tony F.W. Embleton and Lynne Brewster) to replace the departing directors, Lola Cuddy and Jean Nicolas. There was no nominations from the floor.

Elected

10. Other Business

a) Inter-Noise '92 Sharon Abel

An invitation to hold this conference in Canada may be offered. Communications with I/INCE will continue.

b) Honorary Members Winston Sydenborgh

MOTION: That a subcommittee be formed to investigate the requirements and privileges of such group.

MOVED: Winston Sydenborgh Seconded: Harold Forester Carried

c) Canada Wide Science Award Annabel Cohen

MOTION: That $300 over 3 year period for Youth Science Foundation prizes be offered.

MOVED: Annabel Cohen Seconded: Bruce Dunn Carried

10. Other Business (contd)

d) Best Student Presentation — Winston Sydenborgh

This year's committee (Aubry Edwards and Tom Northwood) have expressed the need for guidelines from the Board of Directors regarding this prize.

ACTION: — Board of Directors

f) ISO/ASTM Meetings — Dee Morison/Cameron Sherry

These concurrent meetings with CAA Acoustics Week were announced and the donation from CAA to support them was acknowledged.

Meeting adjourned at 5:40 p.m.

Prepared by:

M.M. Osman
CAA Secretary

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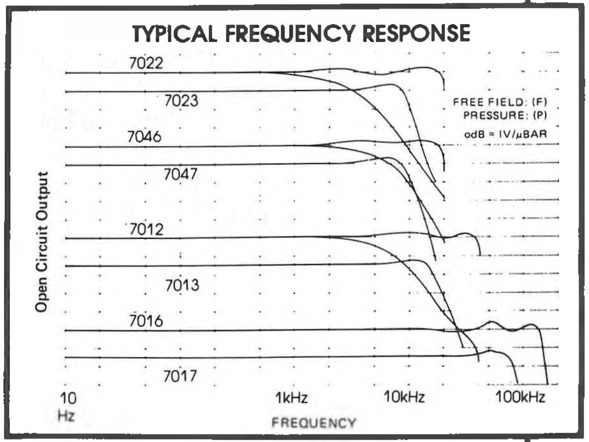

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