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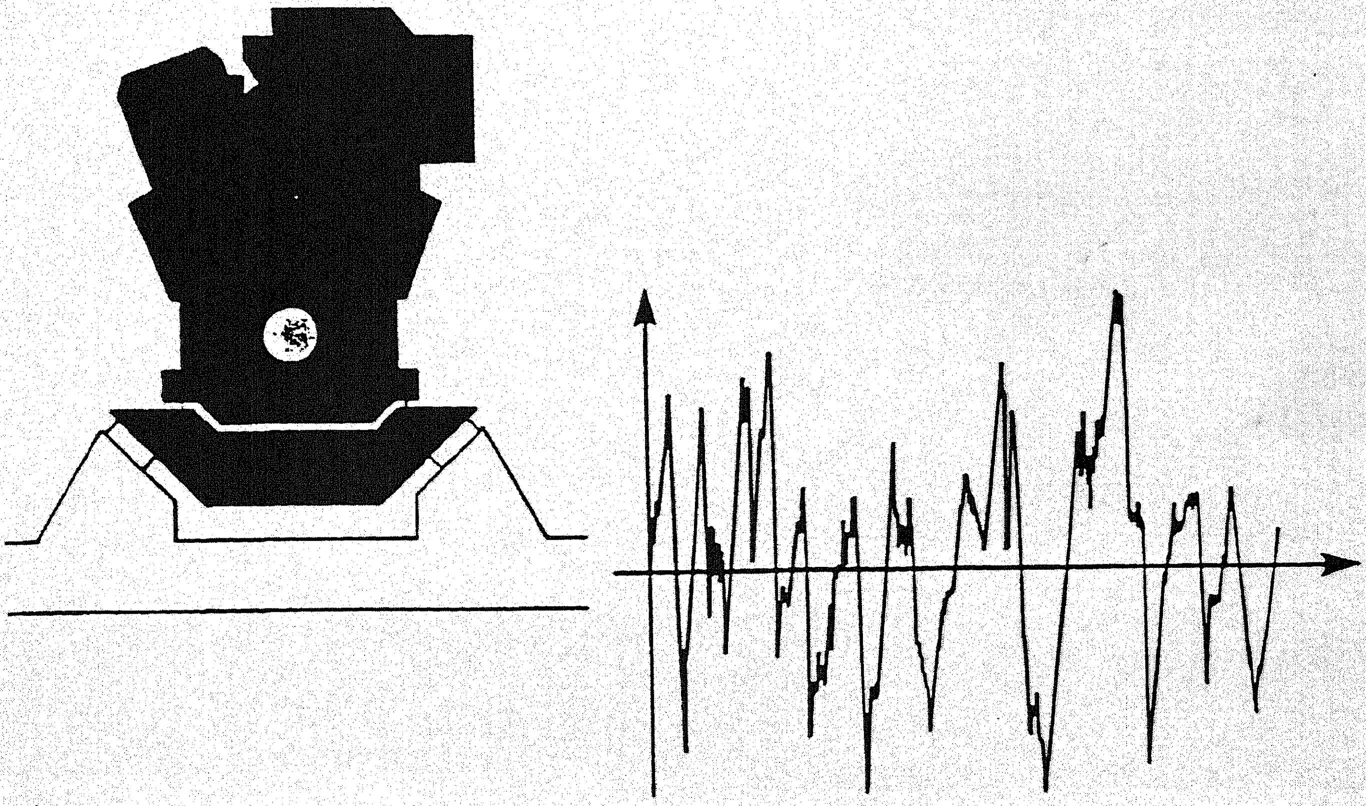
INTERNATIONAL COUNCIL
ON COMBUSTION ENGINES

Standard Method for the Determination of the Structureborne Noise from Engines



CIMAC

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CIMAC is an international organisation, founded in 1950 by a French initiative, to promote technical and scientific knowledge in the field of internal combustion engines (piston engines and gas turbines) This is achieved by the organisation of international congresses and the publication of recommendations compiled by its working groups.

It is supported by engine manufacturers, engine users, technical universities, research institutes, component suppliers, fuel and lubricating oil suppliers and several other interested parties.

The National Member Associations and previous CIMAC Recommendations are listed in the back of this publication.

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Inquiries should be addressed to:

The Secretary General
CIMAC
1, Birdcage Walk
London. SW1H 9JJ

Tel: 44 (0) 171 973 1275
Fax: 44 (0) 171 973 0180

MEMBERS OF THE CIMAC STRUCTUREBORNE NOISE WORKING GROUP

C. Stanworth	(Chairman)	United Kingdom
J. Affenzeller	(Secretary)	Austria
J. Bertran		France
N. Bosch		Switzerland
H. Fujita[1]		Japan
E. Helsing		Finland
G. Mancuso/M. Blason/ V. Loredan[2]		Italy
M. Mors		Germany
T. Nakamura		Japan
P. Pfeiffer		Austria
H. Steenhoek/E.Nijman[3]		Netherlands

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[1] Sadly, Dr Fujita died in March 1991

[2] The member from Italy changed during the currency of the Working Group.

[3] The member from the Netherlands changed during the currency of the Working Group. The Group also received significant assistance from Dr T.ten Wolde of the Netherlands.

FORWORD OF THE PRESIDENT

Following earlier unsuccessful attempts by CIMAC, the British National Committee in 1986 revived the proposal to create a Working Group on structureborne noise. To achieve this they hosted a meeting of interested parties, at which Mr Colin Stanworth agreed to be chairman.

Although there had been CIMAC Recommendations for the measurement of airborne noise from engines since 1970, based on more general standards text method available for determining the extent to which an engine might be capable of causing structureborne noise within the receiving structure in which it was installed. The practical reality was therefore that different manufacturers were adopting different measuring strategies and their customers could require yet other conventions to be applied. This was a confused situation where comparison between similar situations was difficult or impossible.

Fortunately sufficient progress in the international field has now allowed the Working Group to recommend a standard structureborne noise measurement method which can be applied to the majority of engine types represented by CIMAC activities and only the largest engines are excluded.

The Working Group believes that these Recommendations will allow measurement techniques to be harmonised and results from different sources to be compared.

I believe that the issue of these Recommendations by CIMAC represents a significant step forward for both manufacturer and users of internal combustion engines.

M. H. Maghon

NOTE:

CIMAC is aware that this is the first recommendation to be issued in this field in other than draft form. If users have unexpected difficulty in application, CIMAC would like to hear about it so that any emerging problems can be reviewed.

CONTENTS

Standard Method for the Determination of the Structureborne Noise from Engines

High-speed and Medium-speed Engines

1 INTRODUCTION

Noise in buildings, structures, ships, aircraft and land vehicles often arises from the use of internal combustion engines, particularly reciprocating engines, and there can be situations where these are the dominant noise source. Even where it is not dominant it may form an unwelcome background noise. These noises, arising within the building, etc., can be transmitted in at least two ways:

> **1.1** Directly into the surrounding air. This is called airborne sound, and a CIMAC Standard - Recommendations of measurement for the overall noise of reciprocating engines (Air-borne noise) / Recommandations pour la mesure du bruit total des moteurs a combustion interne (Progression des ondes sonors dans l'air) 1970 - already exists for determining the noise output of internal combustion engines. The ways in which this source may be controlled are those of standard acoustic technology, involving, for example, enclosure of the source and the incorporation of sufficient absorbent to limit reverberant noise fields and the transmission of sound along connecting passages/ducts.
>
> **1.2** By the excitation of vibration in the supporting structure. This vibration then passes through the structure as structural vibration, excites in its turn the walls and panels of the structure, resulting in the radiation of so-called secondary sound or structureborne noise.

The capacity of the source of vibration (the engine) to generate vibration in the structure in which it is mounted depends on the amount of motion of the engine at its mounting points, the properties of the engine mounting system, and the mobility of the receiving structure. The vibrations from the engine feet may be in the vertical sense, which is the one most easily visualised, but may also be longitudinal or transverse with respect to the crankshaft axis. The vibration source may also cause rotational input, resolved about each of the three orthogonal axes.

The passage through the structure of any vibration which has been caused in it can be very difficult to control, particularly at low frequencies. There are many possible modes of vibration of the structure which could be responsible for the transmission (compression, torsional or flexural modes) Only breaks in the continuity of the structure are likely to be completely effective, and this is not usually possible.

Damping of the structure may be effective for some propagation modes, particularly at high frequencies/short wavelengths, but will not therefore be sufficiently effective at low frequencies.

In spite of the difficulties in controlling the propagation of vibration within the structure, there are obvious benefits in knowing the characteristic of the engine as a potential vibration source so that a choice of competing units can be made, or the structure and engine mounts can be designed to accept the properties of the engine selected.

1 This CIMAC standard sets out the procedure for measuring the capacity of a medium-speed or high-speed engine to generate vibration and the determination of the frequency limits of validity of the information quoted. The method is not suitable for low-speed engines.

2 TECHNICAL BACKGROUND

On the basis of information currently available, the mandatory requirement of this standard is for translational measurements of mount vibration only (see footnote) in three orthogonal directions. This requirement is based partly on the results of recent calculations and early measurements [ref 1] (which suggest that rotational input is a secondary effect) and partly on the need expressed by manufacturers to keep to a reasonable size the effort required to meet the needs of the standard.

2 The essence of the method is to determine the amount of vibration (in three orthogonal directions) which would occur at the mounting feet of an engine were they to be supported by a mounting system which provided negligible impedance to their motion.

The vibration measurements will be in the three orthogonal axes with respect to the engine defined in ISO 1503,(1977) section 4.

The object of the measurement is to provided values by which engines can be compared, and to allow calculation of the vibration input into a mounting system provided that the source (engine) mounting system and load (receiving structure) impedances are known.

During the test the engine under investigation must therefore be supported by appropriate mounts, be provided appropriately with services (air, fuel, exhaust, coolant, lubricant, electrical supply) and also be equipped with a load system to absorb the power developed. The provision of these services must be by means of flexible connectors which do not influence significantly the vibration of the engine. The engine must be tested with its standard flywheel, and with a sufficiently "soft" coupling to the load. The type and characteristics of the flexible coupling arrangement will be declared in the test report.

In practice, the vibration generated will be a function of frequency, and it will be not be possible to provide a mounting system which will be suitable, or which will allow the engine's vibration performance to be assessed, over the whole range of frequencies.

3 The lower limiting frequency (f_l) will be determined by the characteristics of the mounting system, and this will become progressively too stiff as the frequency falls. The lower limiting frequency (f_l) is the frequency *below* which reliable measurement is regarded as impossible. It is the frequency below which the vibration attenuation across the mounting system for the foot in question and the direction of motion under consideration is less than 10 dB. It is because of the difficulty of providing suitable resilient mounts that this method cannot be applied to low-speed engines.

A test report sheet is attached which may be used for the representation of all the information required.

FOOTNOTE

There may, nevertheless, be a requirement for rotational vibration input to be assessed in particular to be agreed between customer and manufacturer. This is recognised to be particular difficult measurement. Rotational measurements are not covered in this standard; the technique is described in the draft ISO standard DP 9611 [ref 2] and in the report of reference 3.

The upper limiting frequency (f_2) is the frequency above which that part of the mounting foot in contact with the resilient element develops its first vibration mode. When this happens, the accelerometers used for measurement cannot describe reliably the mean motion of the foot.

3 PRINCIPLE OF MEASUREMENT

The principle of the measurement may be understood by reference to figure 1. The upper diagram illustrates the installation of the engine under assessment on a mounting system which is known to be suitable for the test. The isolator must be soft enough to meet the requirement that at all frequencies investigated it does not offer significant load to the vibratory motion of the engine foot. This will be assured if the maximum natural frequency of the engine on its mounts (f_0) is less than 1/3 of the required lower limiting frequency (f_1). The necessary value for f_0 is discussed in section 4.

The lower diagram of figure 1 shows the detail of the mounting foot, with suitable accelerometers attached to it. The accelerometer should be positioned immediately above the effective centre of the mount under investigation, and as close as possible. The accelerometer must be mounted and connected in accordance with ISO 2954. Special attention must be paid to the necessary rigidity of the accelerometer mounting and the type of cable connecting the accelerometer to the recording/analysis equipment.

Where it is not possible to attach a single accelerometer closely above the engine mount, a pair of accelerometers equally spaced either side of the mount may be used, and their output averaged. These accelerometers should nevertheless be fixed as close to the centre of the mount as possible.

The upper limiting frequency, f_2, is the frequency at which modes of vibration develop within the surface supported by the isolator, so that it can no longer be regarded as a rigid body, and the output of the accelerometer(s) cannot be related to the average motion of the foot. This frequency must be determined by a subsidiary investigation to find the first mode of vibration within the surface supported by the isolator. A simple hammer-tap input to the foot may be sufficient, using the installed accelerometers to measure the response. This may be replaced or supplemented by appropriate modal analysis.

Although this section has considered vertical vibration in the example, similar considerations apply to the other directions of motion, which can also be assessed using appropriately placed accelerometers.

4 MOUNTING CONDITIONS

The mounting systems for diesel engines can vary widely, depending on weight, power and application. Whilst the supports for the engine feet are commonly resilient for medium speed and high engines, these mountings may not always be sufficient for the effective assessment of the structureborne noise emission from an engine type under consideration.

In order that the assessment may be carried out to as low a frequency (f_1) as is necessary, the following characteristics of the mounting system should be observed if at all possible:

i The elastic elements should be mounted onto a massive, rigid foundation.

ii f_0, the highest of the six natural frequencies of the engine as a rigid body on its mountings should be sufficiently low.

Practical limits can be set for f_0, however, both by the known characteristics of the human ear, and the fundamental properties of the engine firing cycle.

The lowest frequency which the ear is usually assumed to be able the hear is around 20Hz. Measurement below this frequency is not valuable from the point of view of structureborne noise, and sufficient vibration isolation of the engine feet is not required below this frequency. Thus, the highest natural frequency of the engine on its mounts (f_0) need be no lower than some 7 Hz. There may be situations where the isolation can be limited to higher frequencies, recognising that the lowest frequency which a 2-stroke engine is capable of exciting is the crankshaft rotational speed, whilst the lowest frequency for a 4-stroke engine is half of the crankshaft speed.

The natural frequency (f_0) of the mounting system required for the test to be carried out to a satisfactory lower limit can thus be determined from figure 2 relating f_0 to the lowest service speed of the engine under consideration (remembering that this may be idling speed) the requirement is that all of the fundamental mounting frequencies of the engine should lie on or below the appropriate curve.

The lowest frequency at which reliable determination of structureborne noise can be carried out is about three times f_0. This ensures no dynamic amplification of the measured values due to mounting system resonance in its fundamental mode.

In order that the higher frequency limit for reliable measurement (f_2) should be as high as possible, the mounting feet on the engine should be as rigid as possible.

Cautions

- It should be recognised that there may be regions in the frequency range *between* f_1 and f_2 where the mounts do not provide sufficient (> 10 dB) isolation.

- In order that the true characteristic vibration of the engine foot is determined, the mass and stiffness of the foot in the test mounting (including the mounting flange of the test mount) should be as nearly as possible the same as the mass and stiffness of the foot and flange combination employed in service. In order for f_2 to be as high as possible, these stiffnesses should be high.

5 MOUNT SELECTION

In order to limit the investigation to a manageable size, the mount to be tested should be determined according to the following guidance:

- Up to 4 mounts on the engine; all mounts to be measured.

- 5 to 8 mounts on the engine; the 4 mounts furthest apart to be measured.

- 9 or more mounts on the engine; the four mounts furthest apart, together with the two mounts closest to the centre of gravity to be measured.

- For an engine which has continuous side mounting flange, the above guidance should be applied to the array of positions at which discrete mounts will be attached in service.

Tests on additional mounts may be included by agreement between the customer and manufacturer, particularly in cases where the engine is permanently coupled to other equipment.

6 ENGINE OPERATING CONDITIONS

The mandatory operating situation for structureborne noise measurements, rated speed and 100% load, will be defined by the manufacturer. Other operating points may be agreed between the customer and the manufacturer.

During the course of the measurements, the engine output should not deviate more than 10% from the declared or other agreed engine output. The engine must run at stabilised conditions.

The test must include the following measured conditions of operation:

- Intake temperature
- Ambient pressure
- Humidity
- Cooling water and/or cooling air temperature
- Lubricating oil temperature.

The specification of the fuel which is used during the measurement campaign must also be stated in the test report. The measurement of engine speed and output should be according to the ISO-standard 3046, parts 2 and 3 and is part of the report.

7 MEASUREMENT AND ASSESSMENT

The mandatory test requirements are as follows:-

- Measurement in the three orthogonal axes as defined in ISO 1503 within at least the range of frequencies from f_1 to f_2 appropriate to each axis and type of foot. The steps needed are set out below.
- Determination of f_0.
- Derivation of f_1.
- Determination of f_2 for each foot to be measured, in each coordinate axis.
- Measurement and analysis (or recording and subsequent analysis) of the vibration from each assessed foot in each coordinate direction with the engine running stably at the required operating condition(s)
- Analysis into 1/3-octave band frequency spectra for each case measured.
- Display of one graph per assessed foot overlaying, but nevertheless clearly identifying, the measured 1/3-octave band spectra for each measurement direction (dB re-10^{-9} $m.s^{-1}$) (see footnote) over the range of 1/3-octave bands measured. The frequencies f_1 and f_2 must be identified clearly on the graph as the range of *valid* measurement.

FOOTNOTE

Where a reference level of $5x10^{-8}$ $m\text{-}s^{-1}$ has been used in the past, this will have resulted in levels which are 34 dB lower than those now required.

. One graph per measurement direction, over all of the points measured, showing the mean spectra, together with the maximum and minimum values in each 1/3-octave band. (see example 1)

All of the required information should be included in a test report to the format illustrated in appendix 2.

8 REFERENCES

1 Nijman, E.J.M. - Measurement method for the characterisation of structure-borne sound emission of resiliently mounted combustion engines. CIMAC Congress 1991.

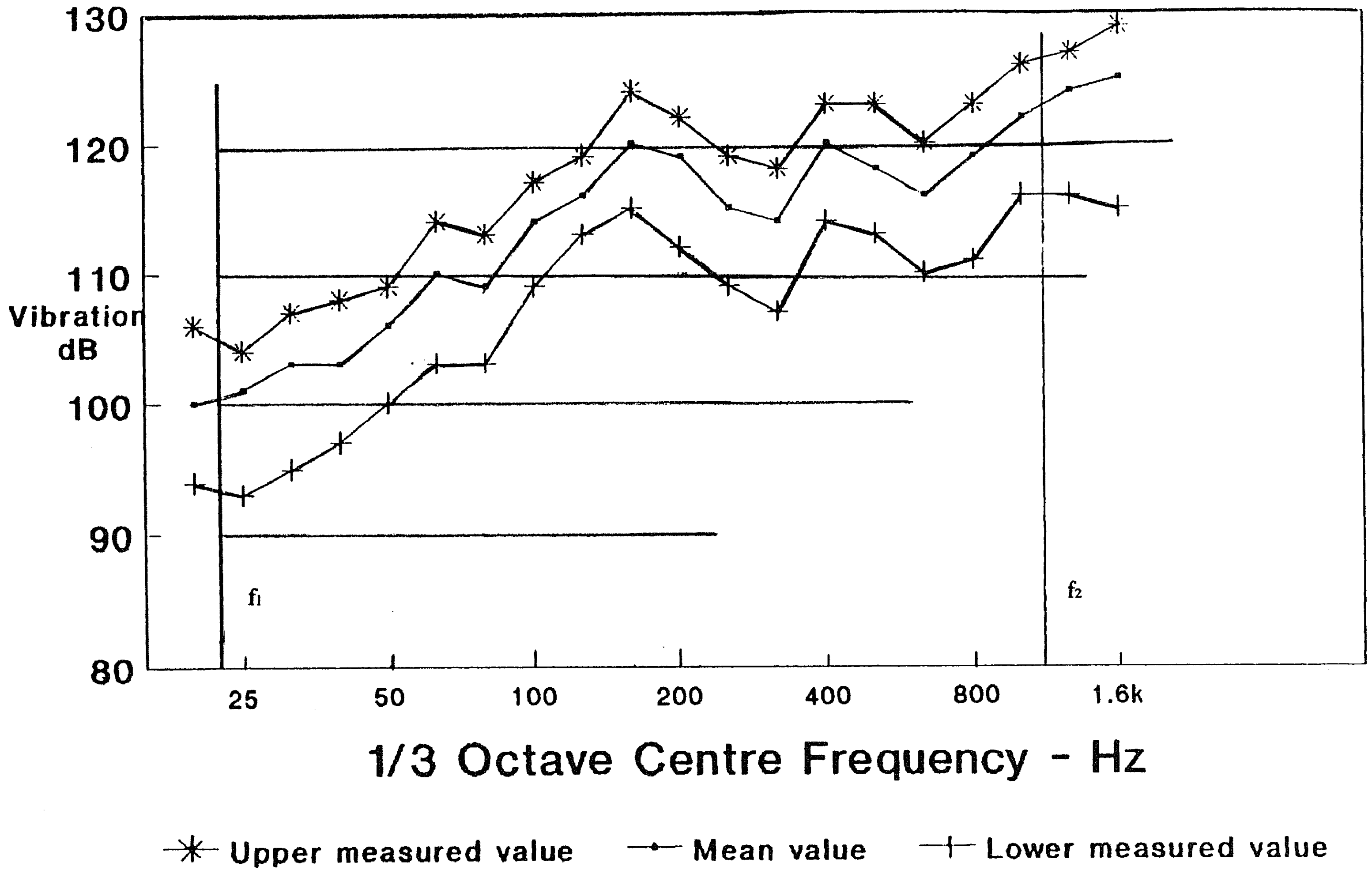
2 International Standards Organisation - Draft Proposal DP 9611

3 ten Wolde, T., and Gadefelt, G. - Development of standard measurement methods for structureborne sound emission. Noise Control Engineering Journal, 1986.

Example 1

Example of Measured values from Test

Mean, upper and lower bounds of values



PRINCIPLE OF THE TEST ARRANGEMENT

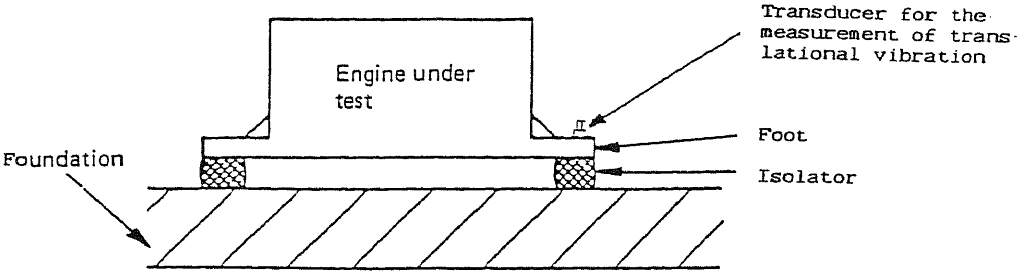
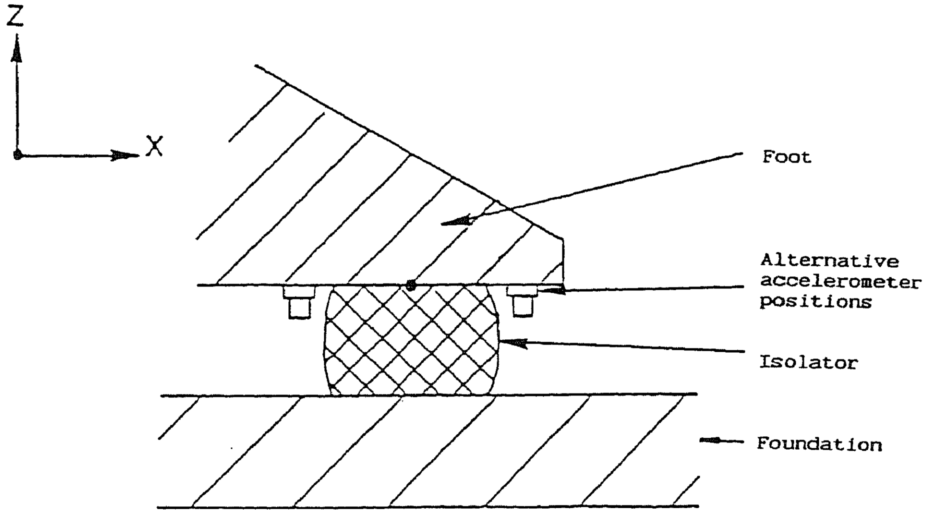
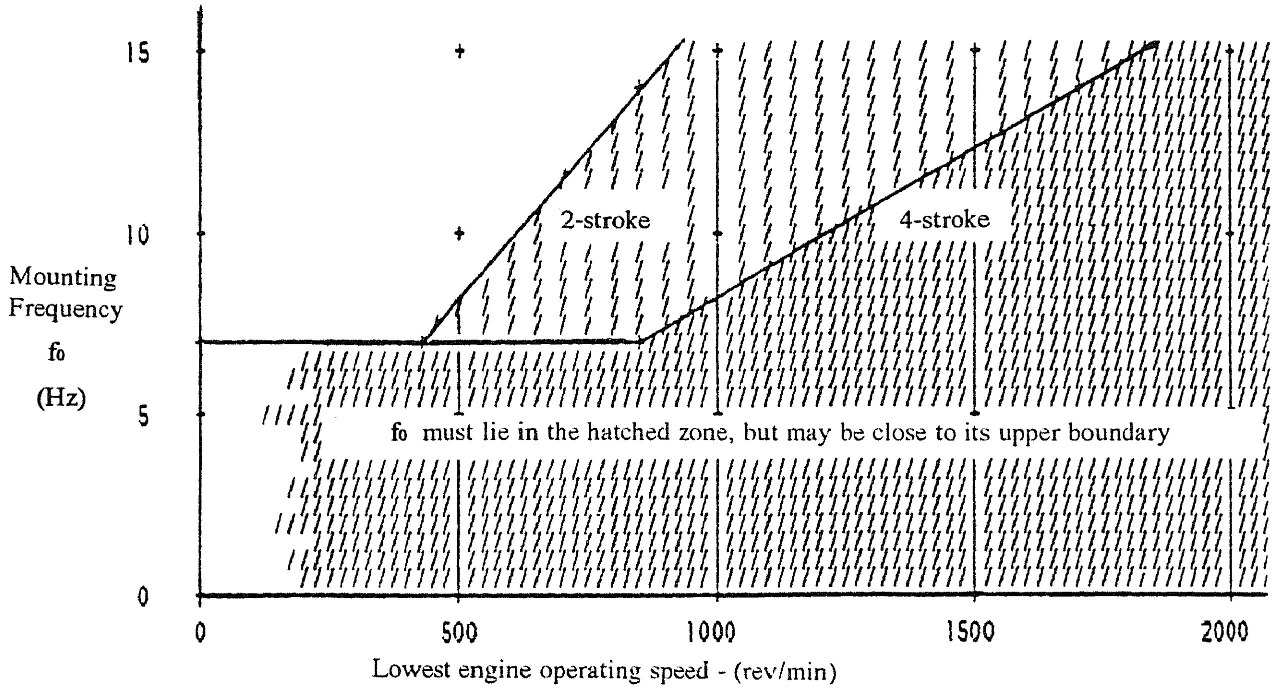


Fig 1

Engine arrangement



Foot arrangement



f_0 must lie in the hatched zone, but may be close to its upper boundary

Fig 2

APPENDIX

ENGINE STRUCTUREBORNE NOISE CHARACTERISATION

TEST REPORT SHEET

1. ADMINISTRATIVE INFORMATION

Measurements carried out by: [Company/Section/People]

on: [date]

in : [location]

Measurements purpose : [standard characterisation]
[customer requirements]

Supervision company :

Engine supplier :

2. GENERAL INFORMATION ABOUT INSTALLATION

2.1 Engine

- Type :
- Serial number :
- Rated speed (rev/min):
- Rated power (kW) :
- Fuel characteristics : [cetane number, viscosity...]
  Enclose special analysis sheet

2.2 Driven System

- Flexible coupling : [including intermediate shaft]
  . Kind :
  . Manufacturer :
  . Type :
  . Drawings :
- Machinery :
  . Kind : [water brake/ac generator/ compressor/gearbox]
  . Manufacturer :
  . Type :

2.3 Machine Resilient Mounting

- Type of suspended machine: [engine alone/engine+rigidly [connected driven machinery]
- Type of supports : [individual/continuous]
  - . Engine : [please attach drawings]
  - . Driven machinery : [please attach drawings]
- Type of mountings :
  - . Manufacturer :
  - . Type :
  - . Number :
  - . Disposition : [explain by a sketch or photograph]
- Type of foundation :
- Total suspended mass : [with fluids, mounting equipment, &c.]
- Calculated (&/or measured) values of the 6 natural frequencies of the suspended machine as a rigid body on its mounts.

3. MEASUREMENT

3.1 Parameter for assessment

- rms velocity

3.2 Measuring equipment

- Sensors : [manufacturer/type]
- Signal conditioning system: [manufacturer/type]
- Recording equipment : [manufacturer/type] [recording mode/frequency range]
- Analysis equipment : [manufacturer/type]
- Calibrations : [sensors] [signal conditioning]

3.3 Units and frequency range

To be presented as rms velocities in 1/3 octave band frequency spectra expressed in dBre 10^{-9}m.s^{-1}

3.4 Measurement points definition

- Total number of mounting feet
- Total number of feet measured
- Location : [explained by sketch]
  - . General location along the machine
  - . Exact position of sensors
- Direction(s) of Measurement : [defined according to a reference] [direction made clear by a sketch]

4.0 RESULTS

For each of the engine operating conditions at which measurements are made, the following information should be presented:-

- Table of engine operating conditions
  - . Power (kW):
  - . Speed (rev/min):
  - . Intake air temperature (deg C)
  - . Atmospheric pressure (kPa)
  - . Humidity (%RH):
  - . Cooling water temperature: [actual/normal] (deg C)
  - . Lubricating oil temperature: [actual/normal] (deg C)
- Table of vibration levels according to 3.3 at all of the points at which measurement was made in vibration velocity dB re 10^{-9}m-s^{-1}
- Graphs:
  - . One graph per measuring point with the vibration velocity spectra (according to 3.3 & 3.4) corresponding to the directions in which measurement was made, all overlaid on the same sheet.
  - . One graph for each measuring direction, over all of the feet measured displaying the mean, maximum and minimum of the power spectral density spectra.

CIMAC NATIONAL MEMBER ASSOCIATIONS

AUSTRIA
Fachverband der Maschinen-und
Stahkbauindustrie Oesterreichs
Wiendner Haupstrasse 63-Postfach 430
A-1045 WIEM/Oesterreich
Tel: 43-222-50105-0
Telex: 111970 fms
Telefax: 43-222-505 10 20
Secretary: Mr R TUPPA

CHINA
Chinese Society for Int. Comb.
Engines
2500 Jun Gong Road
SHANGHI, 200432
Tel: 86-5485856
Telex: 33041 NGNS CN
Telefax: 21-5453132
Secretary: Mr Wang MING-HUA

DENMARK
Danmarks Nationale Komite
c/o Dansk Industri
DK - 1787 København V

Tel: 45-33-77 33 77
Telex: 16068 iadk
Telefax: 45-33-77 33 00
Secretary: Ms Lene HENDRIKSEN

FINLAND
Finnish National Committee of CIMAC
Federation of Finnish Metal, Eng.
& Electrotechnical Inds. - FIMET
Etelaranta 10
SF-00130 HELSINKI 13
Tel: 358-90-19231
Telex: 124997 Fimet SF
Telefax: 358-624462
Secretary: Mr P TUUNANEN

FRANCE
Syndicat Des Constructeurs de
Moteurs a Combustion Interne
39/41, rue Louis Blanc
92400 Courbevoie Cedex 72
92038 PARIS LA DEFENSE CEDEX
Tel: 33-1-47 17 62 81
Telex:
Telefax: 33-1-47 17 62 82
Secretary: Mr JEAN PIERRE

GERMANY
FORSCHUNGSVEREINIGUNG
VERBRENNUNGSKRAFTMASCHINEN e.v
Postfach 71 08 64
D-60498 Frankfurt
GERMANY
Tel: 49-69-6603 345
Telex: 411321 Vdma
Telefax: 49-69-6603 673
Secretary: Dipl Ing H GEISENDOF

GREAT BRITAIN
British National Committee of CIMAC
c/o British Engines Group of SMMT
Forbes House, Halkin Street
LONDON SW1X 7DS
Tel: 44-171-235 7000
Telex:
Telefax: 44-171-235 7112
Secretary: Mr R DAVIS

ITALY
ANIMA
Via L. Battistotti Sassi
11 - 20133 Milano
ITALY
Tel: 39-2-73971
Telex: 310392 Anima
Telefax: 39-2-7397316
Secretary: Dr Ing E MALCOVATI

JAPAN
Japan Internal Combustion
Engine Federation
11-5, 1-Chome, Shinbashi
Minato-ku, TOKYO 105
Tel: 81-3-3574-7882
Telex: J 22443 Hishiju
Telefax: 81-3-3574-7883
Secretary: Mr S MARUYAMA

THE NETHERLANDS
Netherlands National Committee
CIMAC
Boerhaavelaan 40,2713 HX Zoetermeer
P O Box 190 - 2700 AD Zoetermeer
THE NETHERLANDS
Tel: 31-79-531 153
Telex: 32157 FME/NL
Telefax: 31-79-531 365
Secretary: Mrs Saskia van der LEE

NORWAY
DEN NORSKE CIMAC KOMITE
c/o ABB INDUSTRI OG OFFSHORE AS
ABB Dept. Turbocharger
P O Box 6540, Rodekekka
N-0501 Oslo
Tel: 47-22-35 9647
Telex: 71105 kurem n
Telefax: 47-22-35 2190
Secretary: Mr S YGGESETH

POLAND
Polish Society of Mecahnical
Engineers & Technicians SIMP
Combustion Engine Section
ul. Swietokrzyska 14a
00-050 WARSZAWA
Tel: 48-271768 - 263125
Telex: 813225 not pl
816847 zodok pl
Secretary: Prof Dr Ing M ZABLOCKI

SPAIN
Guitierrez Asscunce Corporacion SA
P O Box 57
08480 - L'Ametlla Del Valles
Barcelona - SPAIN

Tel: 34 3 4730307
Telex: 38752 Guaco-E E
Telefax: 34 3 473 01 82
Secretary: To be advised

SWEDEN
Foreningen Svenska Tillverkare
AV Forbranningsmaskiner
Svenska Nationella CIMAC
Kommitten Vasterbergsgatan 3
S-431 69 MOLNDAL
Tel: 46-31-829366
Telex:
Telefax: 46-31-414960
Secretary: Prof L Th COLLIN

SWITZERLAND
Societe Suisse Des
Constructeurs de Machines
Case Postale Kirchenweg 4
CH-8032 ZURICH

Tel: 41-1-38 44 844
Telex: 816519 Vsm
Telefax: 41-1-384-4848
Secretary: Dr J MERMOD

USA
Internal Combustion Engine Division
International Gas Turbine Inst. ASME
345 East 47th Street
NEW YORK 10017
Tel: 1-212-705 7054
Telex: 710-581-5267
Telefax: 1-212-705 7671
Secretary: Mr J CORCORAN

RUSSIA
SovCIMAC
Central Diesel R&D Institute
196158 Leningrad USSR
Moskovskoje shosse 25-1
Tel: 7 95 812 291 2274/6581
Telex: 121569 CNIDI SU
Telefax: 7 95 812 291 2273
Secretary: Dr V BORDOUKOV